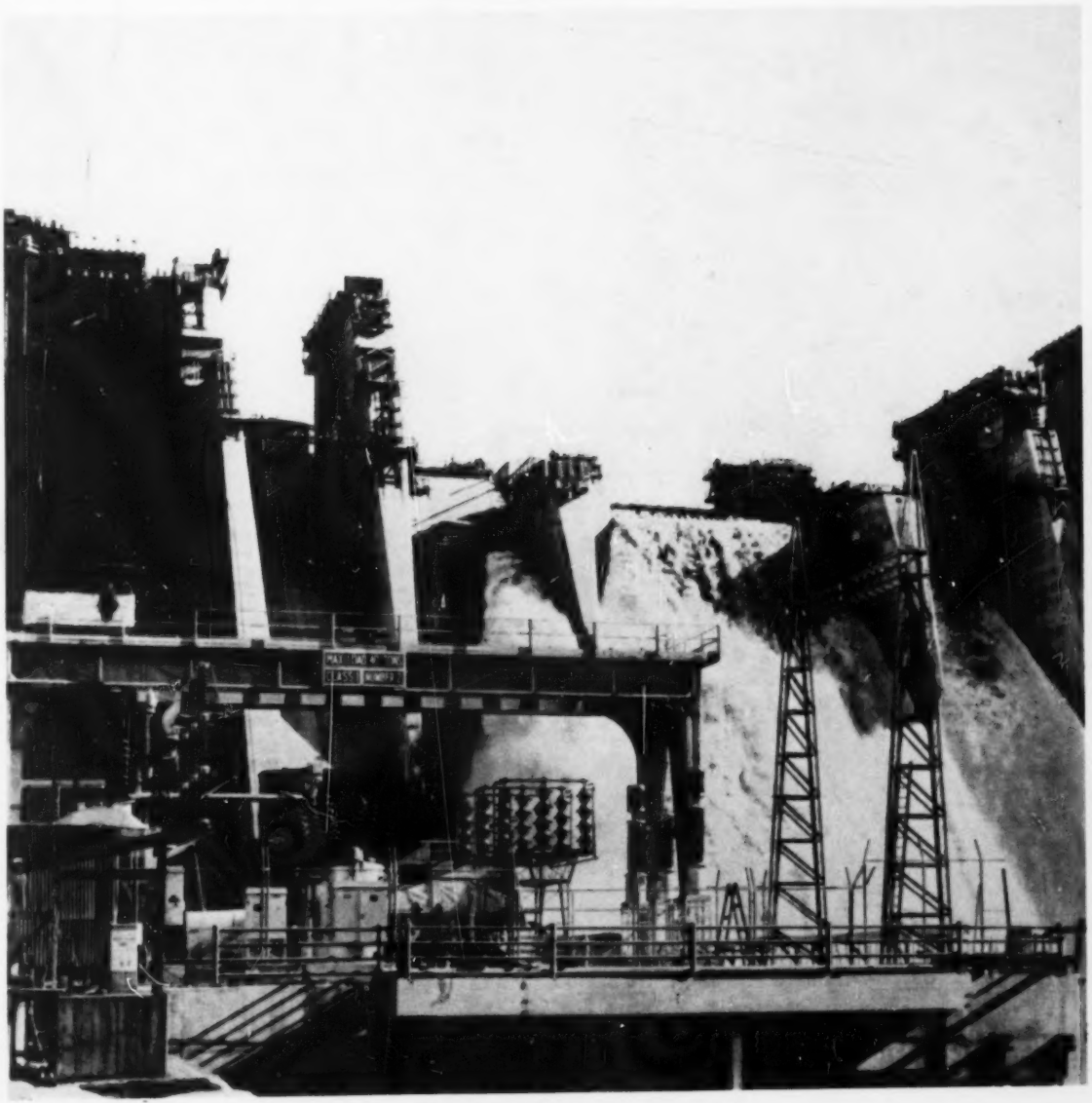
THE BEAMA JOURNAL

FEBRUARY 1960



Australia's First Push-Button Power Station

A QUARTERLY REVIEW OF
BRITISH ELECTRICAL AND ALLIED ENGINEERING

Special Feature in this issue: Industrial Motors

Contents

	1	British Electrical Exports in 1959—A New Record; The Progress of Generation; Lord Nelson of Stafford; Power for Industry
	3	Britain to have World's Largest Generating Sets
	4	'E 3001': British Railways First Operational 25 kV Electric Locomotive
	6	The ERA Electronic Network Analyser
	11	The 21st Anniversary of ASTA
H Myers, B Eng, AMIEE	15	Induction Motors: Some Basic Principles of their Application
C V Hill, B Eng, AMIEE	22	Electric Motor Development and the User
J Shaw	27	Ward Leonard Planer Drives
B J Chalmers, B Sc	29	A Computer Method of Determining the Variation of Induction Motor Magnetisation with Speed
	32	A New Approach to AC Motor Control
	34	Test Plant for Large High-Speed Motors
Sir Lawrence Bragg, OBE, MC, D Sc, FRS	35	The Royal Institution and the Teaching of Science
	37	New Equipment and Processes
	39	A New Road Heating Installation
	40	Electronic Telephone Exchanges
	41	British Automatic Greenhouse at the Ghent 'Floralia'
	42	Book Reviews
	44	Index to Advertisers

Cover Illustration. *Australia's first remote control power station, which has a capacity of 50 MW produced by a 69 000 hp water turbine generator. The station is operated by push-button control from Sydney NSW, 48 miles away, and requires a staff of one. The power plant, switchgear, transformer and control gear were supplied by English Electric Co Ltd under a comprehensive contract worth approximately £1 million.*

Technical Editor: **John Dyer**

Published by The British Electrical and Allied Manufacturers' Association (Incorporated), 36 Kingsway, London, WC2. *Telephone:* HOLborn 0502. *Telegrams:* Perisirius, Westcent, London.

Annual subscription: 10/- post free. Single copies, 2/6. Advertising rates on application. Publication dates: February, May, August, and November.

The Association does not necessarily endorse statements made in the Journal.

THE BEAMA JOURNAL

A QUARTERLY REVIEW OF BRITISH ELECTRICAL AND ALLIED ENGINEERING

Volume 67 : Number 1 : February 1960

British Electrical Exports in 1959: A New Record

Official figures just released reveal that exports by the British electrical and allied industry in 1959 achieved an all-time record with a total value of £285·2 million. This is £6 million higher than the previous record set up in 1957, and £9 million more than the 1958 total.

As we have pointed out on previous occasions, the figures issued by the Board of Trade deal with 'direct' exports only and take no account of electrical equipment which is exported as part of other engineering products. While it is impossible to arrive at the exact value of these 'hidden' exports, they can be reliably estimated at a figure which would bring the value of all electrical equipment exported from the UK to a total well in excess of £300 million for the year.

Power plant and industrial machinery—which includes generators, motors, switchgear and transformers—amounted to £93 million, and notable increases in this group were exports of steam and water turbines—£14·7 million as compared with £10·7 in 1958—and electric motors with an increase of £1·6 million. Electric wires and cables were exported to a value of £25 million.

British electrical equipment is sold in every part of the world. The leading markets last year were India, Australia, South Africa, the United States, Canada, New Zealand and Rhodesia, and although detailed figures giving the totals in individual countries are not yet available, sufficient information exists to suggest that electrical exports to the North American continent were of the order of £30 million—over 10 per cent of the total and approaching the combined total to Australia and New Zealand last year.

The electrical and allied industry is one of Britain's largest exporting industries and its products accounted for more than 10 per cent of the whole of the exports from the UK last year. Taken over the whole of the industry's production, the proportion which is exported amounts to between 20 and 25 per cent.

Such an achievement in the face of keen competition from other exporting countries, the ever growing degree of local manufacture in many of our best markets, and import restrictions, emphasises yet again the high reputation which British electrical and allied equipment enjoys in the markets of the world.

The Progress of Generation

On several occasions recently we have commented on the very great advances which the British electrical manufacturing industry has made in the design and construction of generating equipment. It was only about ten years ago that the 60 MW unit was regarded almost as a 'standard' size for generating stations in this country, and only about two years ago that 100 MW and 120 MW sets were designated as 'large'.

These have now been eclipsed, first by the series of 200 MW units planned for commissioning during the next few years ; then by the first 350 MW single-shaft steam turboalternator ordered last year for the new Drakelow C power station (which will ultimately have two such units), and finally by the two 550 MW cross-compound turboalternators, each fed from a single boiler, now on order for the Thorpe Marsh station. This last achievement gives Great Britain the distinction of having under construction the largest boiler and generating units of their kind in the world.

Technological progress is not, however, measured by size alone. The objective is always that of maximum generating efficiency, and progress measured by this standard is no less striking. The average thermal efficiency (sent out) of *all* steam stations in England and Wales—large and small, new and old—has risen from 20·9 per cent in 1948 to 26·1 per cent in 1959, but a more accurate picture of recent progress is given by the performance of 20 of the newer and larger stations (*ie* those brought into service during the last 10 years), which show an average thermal efficiency of 30·3 per cent, with the best station showing 33·04 per cent.

Even so, the manufacturers of one of the new 550 MW units have publicly proclaimed their expectation of an increase of 7 per cent in overall station efficiency over the most efficient station now in operation.

Figures now available from the Central Electricity Generating Board show that during 1959 a total of 21 turboalternators with an aggregate installed capacity of 1 775 MW, and 23 boilers with an aggregate evaporative capacity of 14·7 million lb (6 667·8 kg) an hour, were installed at 15 power stations in England and Wales.

Naturally, a notable feature of the 1959 programme was the number of large generating sets commissioned.

These comprised three of 100 MW, five of 120 MW, and one of 200 MW—this being the first of the series of such units mentioned earlier.

The story of British generating progress also continues overseas, for the demands of the home stations, great as they are, do not by any means absorb the high level of plant production achieved during 1959. In such projects as Kariba, where the first British-built 100 MW water turbine driven generator was commissioned last December ; the Richard L Hearn station in Toronto, which now has four 200 MW turboalternators which were built in England, and the 500 MW set now being built in this country for export to the USA (to mention only three out of many other similar projects), British equipment gives further practical evidence of leadership in this important field.

Lord Nelson of Stafford

THE BEAMA JOURNAL on behalf of the British electrical and allied industry offers congratulations to Sir George Nelson, Bart, on the barony conferred on him by HM The Queen in the New Year Honours List.

Lord Nelson is widely known both at home and abroad, not only as Chairman of the English Electric Group of Companies, but also as one of the most distinguished personalities in the electrical manufacturing industry and one of the greatest industrial leaders of the present time.

The Rt Hon Lord Nelson of Stafford

After a brilliant academic career, he rose rapidly to senior executive positions in the electrical industry, and in 1930 was appointed managing director of the English Electric Co Ltd. Three years later he was Chairman. This was at a time of economic depression between the two world wars and his primary task was to revive the then waning fortunes of the company.

His unique qualities as a highly trained engineer and a man of immense energy, enterprise and administrative ability have quite literally 'put English Electric on the map', since to-day there is scarcely any country in the world without English Electric equipment of one kind or another, be it electricity generating plant; most forms of electric and diesel-electric traction ; industrial and domestic electric equipment ; electronic, radio, radar and television apparatus, and aircraft.

Lord Nelson is a powerful and sincere advocate of international and Commonwealth cooperation and development, to which both he and his companies have constantly added the strength of personal service and practical endeavour.

He has been a member of the BEAMA Council since 1932 ; was Vice-President from 1936 to 1949 ; President from 1950 to 1953, and was re-elected as a Vice-President in 1954. He is a past President of the Institutions of Electrical Engineers and Mechanical Engineers and was elected President of the Locomotive and Allied Manufacturers' Association in January, 1958. He was President of the Federation of British Industries from 1943 to 1945 and has been a member of the Grand Council of the Federation for the past 14 years.

A knighthood was conferred on him in 1943 in recognition of the public work he had continually undertaken, and he was created a baronet in 1955.

In assuming the title of Lord Nelson of Stafford he reaffirms his long and close association with that part of England which has one of the English Electric Company's biggest engineering works and indeed its headquarters, and with the Borough which in 1956 made him an Honorary Freeman of Stafford.

Power for Industry

Wherever power is required for almost every industrial application, the ac induction motor occupies a firmly established position. All over the world British-built motors have proved their efficiency and reliability over long years of service, often in the most difficult and arduous conditions.

Special articles in this issue give a broad survey of the history of the induction motor, its progress in design and construction and its many general and specialised applications. The important question of standardisation is also dealt with in some detail.

These articles were arranged in consultation with the BEAMA sections concerned, the member-firms of which are :

Dynamo and Motor Sections

Allen, W H, Sons & Co Ltd
Associated Electrical Industries Ltd (Motor and Control Gear Division)
Bruce Peebles & Co Ltd
Brush Electrical Engineering Co Ltd
Bull Motors (E R & F Turner Ltd)
Crompton Parkinson Ltd
Electric Construction Co Ltd, The
Electro Dynamic Construction Co Ltd
English Electric Co Ltd, The
General Electric Co Ltd, The
Greenwood & Batley Ltd
Harland Engineering Co Ltd, The
Higgs Motors Ltd
Houchin Ltd
Lancashire Dynamo & Crypto Ltd
Laurence, Scott & Electromotors Ltd
Macfarlane Engineering Co Ltd
Mather & Platt Ltd
Mavor & Coulson Ltd
Mawdsley's Ltd
Newman Industries Ltd
Newton Bros (Derby) Ltd
Parsons, C A, & Co Ltd
Reyrolle, A, & Co Ltd
Tuscan Engineering Co Ltd

Britain to have World's Largest Generating Sets

THE new power station now under construction by the Central Electricity Generating Board at Thorpe Marsh, near Doncaster, Yorkshire, will be outstanding even in this age of rapid advances in the design of steam generating plant. The station will have the distinction of housing the world's largest single-furnace boilers and the world's largest conventional cross-compound turbo-alternators generating at 50 c/s. It will also have the largest generator transformers ever installed in the UK.

Thorpe Marsh will have an ultimate capacity of 1 100 MW and will therefore rank as one of the largest power stations in the world. Moreover, this output will be achieved by only two generating sets, each of 550 MW capacity. Site work was started about a year ago, and the first set is scheduled for commissioning in 1963.

The boilers are to be built by International Combustion Ltd and Babcock & Wilcox Ltd respectively, and the latter firm has supplied the following details.

Main Features of the Plant

The boiler will be a pulverised coal fired Radiant type rated at 550 MW, consuming about 200 tons of coal an hour (5 000 tons a day) and producing 1 675 tons of steam an hour. This is the greatest output ever required from a single boiler.

Careful design has achieved a high degree of compactness; even so it will be 170 feet (52 m) high when completed. It will have a single fusion-welded hp steam drum 130 feet (39 m) long and weighing some 265 tons which will be lifted into position during erection 160 feet (49 m) above ground level.

Steam will be supplied to the turbine at a pressure of 2 400 lb/in² (169 kg/cm²) and a temperature of 1 055 deg F (568 deg C), with reheat to the same temperature.

The two turboalternators will be supplied by C A Parsons & Co Ltd and the Turbine Generator Division of Associated Electrical Industries Ltd (AEI) respectively. Both have a similar specification, but the Parsons generator will be a single-speed machine running at 3 000 rev/min, while the AEI set will be a two-speed machine. Both are cross-compound machines consisting of a multi-cylinder turbine divided into two sections on separate lines, each driving a 275 MW alternator.

The two sections of the AEI turbine will be cross-compounded with a single-flow hp cylinder and a double-flow first ip cylinder on one line running at 3 000 rev/min, and two single-flow second ip and two double-flow lp cylinders on the other line running at 1 500 rev/min. Steam from the boiler is expanded through the hp cylinder and reheated before expanding through the first ip cylinder. The steam then passes to twin second ip cylinders on the low-speed line and thence to the lp cylinders before exhausting to the condensers.

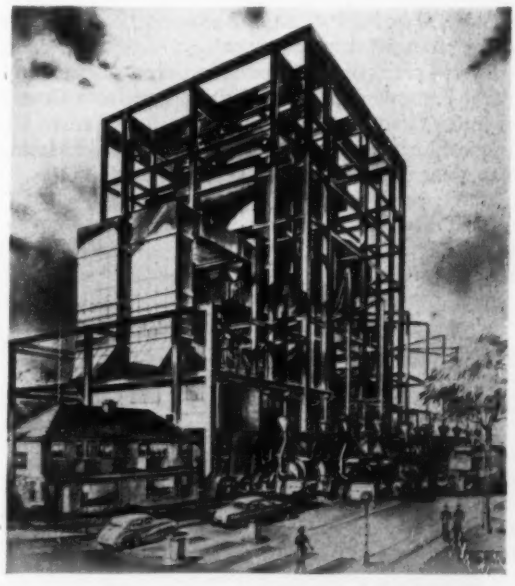
The two generators, although of equal output, will differ in size because they run at different speeds, but both will have water-cooled stator windings—a system introduced by AEI. The cooling water is circulated through the live conductors, which are in the form of thick walled copper tubes of rectangular cross-section. The other parts of the generator are cooled by hydrogen at a pressure of 30 lb/in² (2·1 kg/cm²) gauge. The gas is circulated inside the sealed casings of the generators by fans mounted on the ends of the rotors and is forced through ducts in the stator core and through the rotors, where it is brought into direct contact with the copper of the rotor windings. The hydrogen is cooled before recirculation by banks of water-cooled tubes within the generator casing.

The unit is expected to operate with an increase in overall station efficiency of 7 per cent over the most efficient station listed in the CEGB's last annual report.

The transformers mentioned earlier are two 310 MVA generator transformers and will be supplied by the English Electric Co Ltd. They will each have a shipping weight of 170 tons.

They will step up the generator voltage from 18 kV to 295 kV for transmission to the supergrid; they will be equipped with on-load high-speed tap changers and will be cooled by pumped oil circulation through water coolers.

Each transformer will be manufactured and fully tested at the company's Stafford works, and the testing will include a full load loss heat run. English Electric claim to be at present the only manufacturers in the United Kingdom equipped to carry out this test at a rating of 310 MVA and above.



An artist's impression indicating the great size of the boiler designed to drive a 550 MW turbogenerator. The steel structure weighs over 12 000 tons and includes some 270 miles (435 km) of steel tubing

'E 3001'

BRITISH RAILWAYS' FIRST OPERATIONAL 25 kV ELECTRIC LOCOMOTIVE

THE ceremony of handing over to British Railways the first ac main line electric locomotive took place on 27 November, 1959, when Lord Chandos, Chairman of Associated Electrical Industries Ltd (AEI) formally asked Lord Rusholme, Chairman of the London Midland Area Board, to accept its delivery, and presented him with a special key to the locomotive.

E 3001—which is its official number—is the first of a series of 25 main line locomotives to be supplied to British Railways by the Traction Division of AEI, which now incorporates the Traction Departments of the British Thomson-Houston Co Ltd and the Metropolitan-Vickers Electrical Co Ltd. The mechanical parts were sub-contracted to the Birmingham Railway Carriage and Wagon Co Ltd of Smethwick, Staffs.

Of these 25 locomotives, 23 will be Type A, geared for a top speed of 100 miles/hour (161 km/h), and two will be Type B, geared for a top speed of 80 miles/hour (129 km/h). They are intended for use on the new electrified main line system between London, Manchester and Liverpool (scheduled for completion by 1964—some four years earlier than originally planned), but will be equally suitable for use in the later electrification schemes.

E 3001 is thus the first *operational* 25 kV ac locomotive in the service of British Railways. E 1000, which was described in our February, 1959, issue,* was an experimental model converted from its original design of a gas turbine locomotive, and its primary role has been that of training the instructors, motormen and guards who will operate the new electric services.

The new series of locomotives has been designed to the general requirements of the British Transport Commission under the overall direction of Mr S B Warder, Chief Electrical Engineer, and Mr J S Harrison, Chief Mechanical Engineer, British Railways Central Staff.

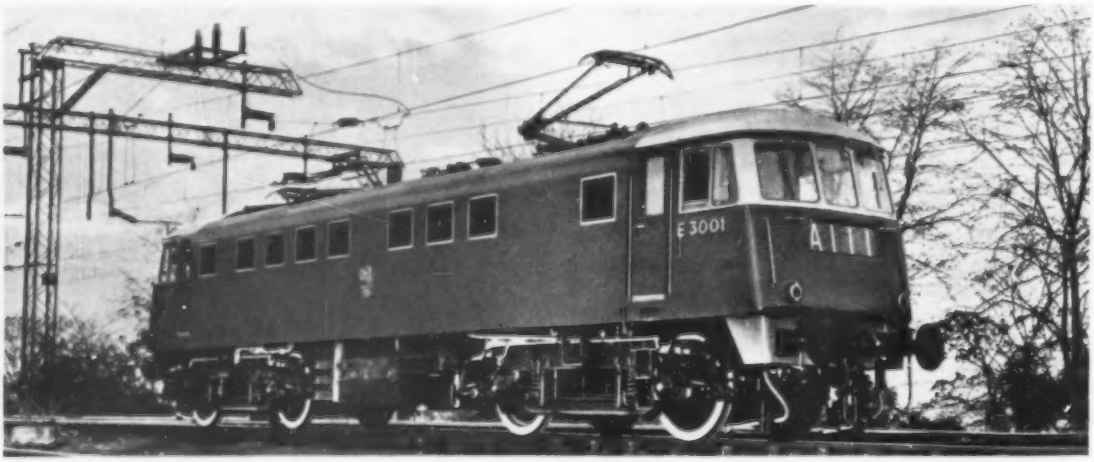
*THE BEAMA JOURNAL, **66**, No 1, pp 30-32

The principal technical details of the locomotives are as follows:

	Type A	*Type B*
Wheel arrangement	Bo-Bo	Bo-Bo
HP at 1 hour rating of traction motors	3 680	3 680
Top speed—miles/h	100	80
km/h	161	129
Weight—tons	80	80
Brakes	Vacuum controlled	Straight air on locomotives
Max. tractive effort at peak notching current	48 000 lb 21 772 kg	60 000 lb 27 216 kg
Tractive effort at continuous rating of motors	20 000 lb 9 072 kg	24 000 lb 10 886 kg
Speed at continuous rating of traction motors	60 mile/h 97 km/h	49 mile/h 79 km/h

The locomotive is designed primarily for ac operation at a line voltage of 25kV, 50 c/s. However, it has also to develop its full output at 6·25 kV because certain sections of the overhead line have limited electrical clearance under some bridges and tunnels and are therefore fed at this reduced voltage. For this purpose, the main transformer primary wiring is arranged in four sections which are connected in series for the 25 kV and in parallel for the 6·25 kV supply, the change-over being effected automatically by an oil-immersed off-load change-over switch controlled by a voltage selector relay.

Current collected from the overhead wire by pantographs of the Stone-Faiveley AMBR pattern is fed to the main transformer through an air-blast circuit breaker mounted on the locomotive roof. The output of the transformer is converted to dc for the traction motors by three air-cooled six-anode pumpless steel tank mercury arc rectifiers, diametrically connected in



parallel so that each tank has three anodes in each half cycle. Load-sharing reactors are provided to ensure current sharing between tanks and individual anodes, and smoothing chokes are also provided.

The four traction motors are connected permanently in parallel. They are six-pole series-wound machines specially developed for operation on a rectified 50 c/s single phase supply, forced-ventilated, and designed for long periods of operation between overhauls. This has been achieved by using, among other things, class H insulation and special lubrication arrangements. The ratings of the motors are:

Continuous rating ..	975V	700A	847 hp
1 hour rating	975V	760A	920 hp
Gear ratio, type A ..	29/76		
,, ,, ,, B ..	26/83		

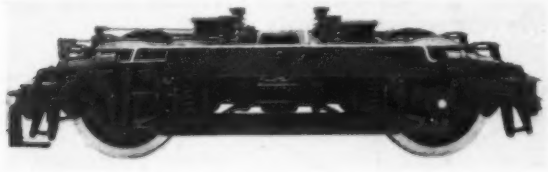
The motors are fully spring-borne in the bogies, the drive being transmitted to the road wheels by a quill drive developed from the Alsthom pattern.

A camshaft control unit, actuated by the driver's master controller, provides 37 accelerating notches and 2 field weakening notches. Voltage control is by on-load tap-changing on the low voltage side of the transformer winding and the output is fed to the rectifiers through two high-speed circuit breakers, thus rendering anode fuses unnecessary. In addition to giving protection against backfires, these breakers are also used as contactors during ordinary locomotive operation, so that there is no need to provide individual motor contactors.

The auxiliary equipment includes two traction motor blowers, three rectifier cooling fans, two transformer oil cooling radiator fans, and a transformer oil circulating pump which are driven by ac single phase capacitor-start-and-run motors, while two exhausters and one compressor are driven by dc motors. One exhauster is battery fed; the other exhauster and the compressor are fed from the ac supply through germanium rectifiers. The battery is floating continuously on a battery charger of the magnestat type which also incorporates a germanium rectifier.

Mechanical Features

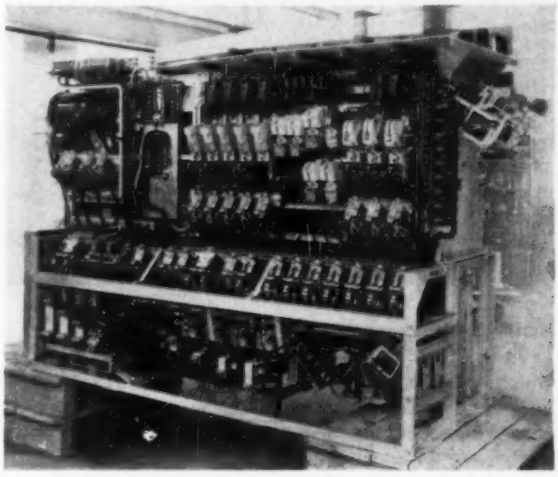
The locomotive is of the double ended type, and the driving compartments at each end are connected by a corridor. Behind each compartment is a space in which



The locomotive bogie

are housed the compressor, exhausters and traction motor blowers and other equipment. The central compartment, to which access is obtained by means of an interlocked door at No 2 end, houses the control gear, transformer and rectifiers. The interlocking allows access to the compartment only when the pantographs are lowered and the high voltage equipment is earthed.

The complete body of the locomotive is designed as a weight-carrying structure and consists of a fabricated underframe with side members and centre sills of rolled steel channel section. Between the bolsters, the side-frames (which are riveted to the underframe) are of braced frame construction with deep section cantrails, joined at



A view of one side of the main control unit

intervals by transverse members which also carry the pantograph feet, thus providing a structure combining lightness with high resistance to buffing shocks and eccentric loading. The transverse members, which also carry the roof traps, are removable so that the body of the locomotive can be completely opened at the top if removal of the equipment should be necessary.

The driving cabs are in accordance with the size and layout decided upon by British Railways as the standard for this type of ac locomotive; they give unusually spacious and comfortable accommodation for the crew.

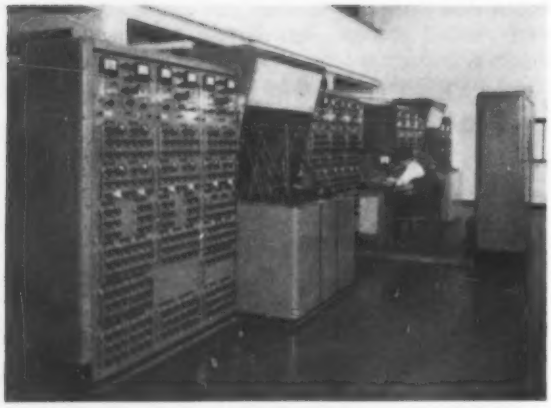
In order to reduce weight, the maximum use has been made of glass-fibre construction for such items as cab roofs, doors, bulkheads, air ducts and even the transformer oil conservator tank.

Bogies and Suspension Details

The bogies are of special interest as the suspension and the flexible drive from the frame-mounted motors utilise the well-known Alsthom principles incorporating rubber bearings and pivots. The bogie frame is fabricated from 'Corten' steel and the design is such that the welding between side frames and cross members is carried out at points remote from the areas of maximum stress.

The traction motors with their gears and quill shafts are carried on 3-point pre-loaded rubber mountings in the bogie frames and are coupled to the road wheels by Alsthom type link drives. The wheel sets are carried in double row spherical roller bearing axle boxes which are connected to the bogie frames by rubber bushed radius arms giving a cushioned resistance to lateral impacts. The primary coil springs are mounted on equalising beams underslung from the axle boxes in rubber 'chevron' mountings and hydraulic dampers are fitted. Separate brake cylinders are provided for each wheel and the use of reaction support for the inner hangers gives a very simple brake rigging.

(Continued at foot of page 10)



The ERA Electronic Network Analyser

SOME five years ago the Electrical Research Association gave the first news of its electronic network analyser* which was then under construction. Towards the end of last year, after the completed analyser had been in successful operation for some time, the Association invited the technical press to see ENA (as it is familiarly known) in action.

In his introductory remarks, Dr H G Taylor, the Director of the Electrical Research Association, touched briefly on the organisation and scope of the Association, and said that it was impossible to evaluate its work for the electrical industry, but in one field alone—that of research on cables—it had saved the country more than the whole cost of the Association during the 38 years of its existence.

When they started to build ENA, he said, they set out to provide characteristics in an analyser which had never been provided before. The chief of these was a continuously variable frequency supply, and no other analyser in this country has this very valuable feature which enables ENA to deal with ease with harmonic and resonance problems. Another was the feature for studying transient as well as steady state conditions, and a most important feature was its high degree of accuracy, which, he said, was better than that of other similar analysers.

ENA has been built entirely by the staff of the ERA under the guidance of an expert committee, and as Dr Taylor pointed out, much care was taken in choosing operating conditions and selecting the network components so that a large number of network elements of high accuracy suitable for use over the whole frequency range could be provided. Here is a brief description of the equipment.

The base quantities of the analyser are as follows:

Voltage	... ...	0·5 V
Current	... ...	5 mA
Power	... ...	2·5 mW
Impedance	... ...	100 Ω
Frequency	... ...	1 592 c/s (ω=10 000)

The frequency range is 159·2 to 15 920 c/s (ω=1 000 to ω=100 000).

It will be noted that the base values of voltage, current and power are much smaller than is usual in network analysers. They were chosen to make it easier to provide the large number of high-quality inductors which had to work over the whole frequency range. The rather low value of base impedance was selected to reduce trouble from coupling between units. The frequency range lies in the range of audio frequencies and is satisfactory from the point of view of keeping stray reactances small.

The base values of the various quantities may represent any value in the system under investigation. For instance, the analyser base voltage may represent 33 kV in one study and 275 kV in another, or indeed both voltages in different parts of the same network. The base power may represent 100 MW, 1 000 MW, or any other value. In the same way, the analyser frequency range may represent any frequencies in the actual system, subject only to a maximum ratio of 100 : 1 between the highest and lowest frequencies.

The complete equipment comprises 18 energising or generating sources and about 430 passive network units. (The latter are those having no internal source of generation, as for example resistors, inductors, capacitors and transformers.)

The network units are arranged in four sections grouped in a back-to-back arrangement which enables the length of the measuring leads and interconnections to be kept to a minimum. Fig 1 shows the connections between the various parts. Each section may be used with either the steady-state or the transient measuring apparatus at will, and unless a very large number of units is required, a steady-state and a transient problem may be in progress simultaneously.

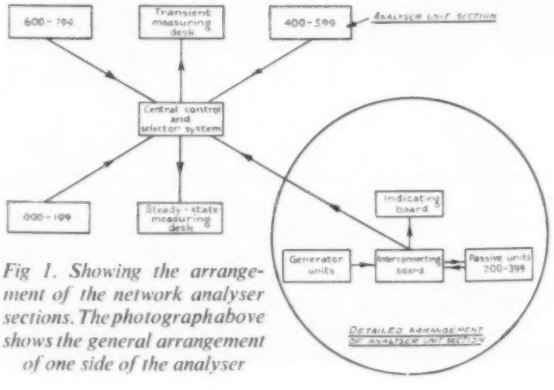


Fig 1. Showing the arrangement of the network analyser sections. The photograph above shows the general arrangement of one side of the analyser

*THE BEAMA JOURNAL, **62**, No 3, pp 105-109

The question of accuracy has received special attention. The tolerance of the components themselves is $\pm$ 1 per cent, and the strays do not materially exceed 0·1 per cent of the corresponding base quantity; thus stray resistance should be less than 0·1 ohm; stray capacitance less than 1 000 pF, and stray inductance less than 10 μH.

As the measuring system has to give a clear and accurate indication of all the measured quantities over the whole of the frequency range with a resolution of 0·1 per cent of the base value, ordinary pointer instruments were regarded as out of the question.

A servo-balanced ac bridge was therefore developed on the principle illustrated in Fig 2. A reference voltage, synchronous with the voltages in the network, is compared with the unknown voltage from the network. The vector difference is separated into components which are in phase and in quadrature with the reference voltage. The in-phase and quadrature components are caused to operate servo-motors which adjust respectively the amplitude and phase of the reference voltage until it is equal to the unknown voltage. The positions of the reference potentiometer and phase shifter then indicate the amplitude and phase of the network voltage which is being measured.

Current is measured in the same way, using the voltage drop across a 20 milliohm resistor in series with each unit.

The sensitivity of these bridges is such that the current measuring bridge is capable of detecting changes of 0·016 μV.

Active and reactive power are not measured directly in the network but are obtained by a small special-purpose analogue servo-multiplier which obtains its input information from the shaft positions of the voltage- and current-measuring bridges (Fig 3).

A constant 50 c/s voltage is fed to two linear potentiometers and one sine-cosine potentiometer connected in cascade. The shafts of these potentiometers are ganged to the voltage- and current-measuring bridges so that signals proportional to active and re-active power are obtained. These signals are compared with the original input voltage by simple servo loops which give shaft rotations proportional to active and reactive power.

For the transient measuring system, generators

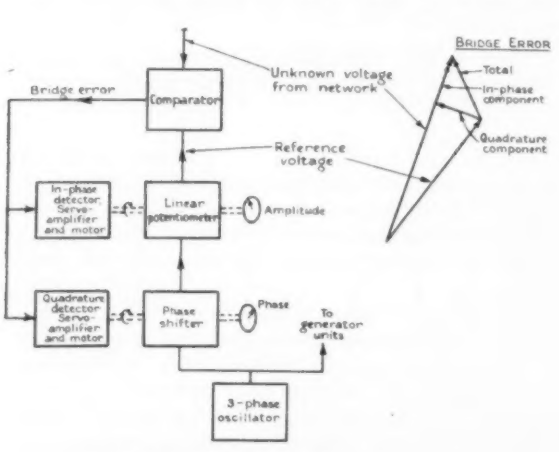


Fig 2. Principle of servo-bridge measurement

capable of providing a range of the more generally useful transient waveforms have been installed. The transients are repeated at intervals of between 10 and 100 cycles of the network frequency with which they are synchronised.

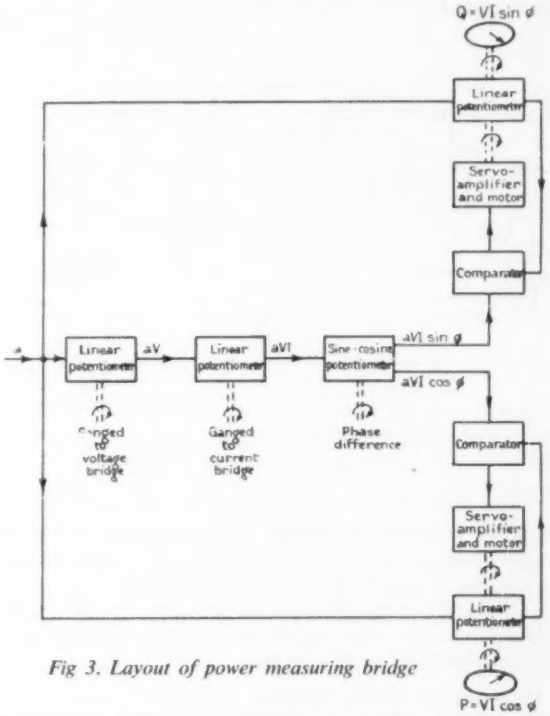


Fig 3. Layout of power measuring bridge

These waveforms may therefore be injected into a network which is already energised by the steady-state generators.

The resulting voltage waveforms are displayed on a cathode-ray oscilloscope, and a synchronising signal enables any cycle or part of a cycle in a sequence to be examined.

The capabilities and versatility of the analyser were demonstrated by setting up and solving a number of diverse problems, of which the following are typical.

Power System Studies

A common problem in power system engineering is that of determining power flow in a system which has to supply specified loads.

Fig 4 depicts a fictitious power system having four generators and five loads. The data given for such a study include: (a) Details of the active and reactive power for each load, (b) information on how this is to be apportioned between the various generators, and (c) restrictions on the amount by which busbar voltages may deviate from their normal value.

The demonstration showed:

(a) how the network analyser units are assigned to represent the various parts of the system,
(b) how the interconnection of the units is organised, and
(c) how the impedance values are adjusted,
(d) how the generation is adjusted,
(e) the measurement of busbar voltages and the power flows in the various lines.

The circuit was changed by disconnection of the Bigton/Whipping 132 kV line, as could occur following a fault on the line. Power flows were remeasured and it was shown that the Bigton 132/33 kV transformer was overloaded.

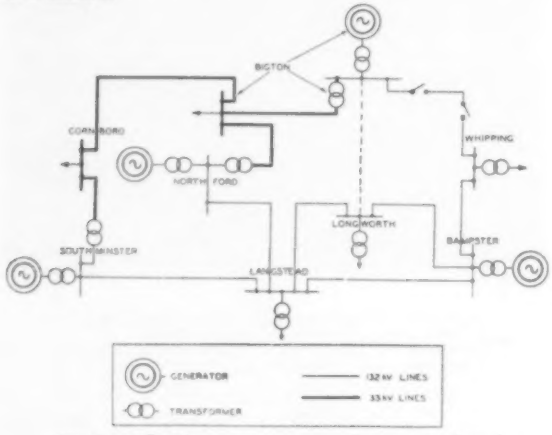


Fig 4. A fictitious power system for a typical study

The network was then modified by the addition of a 132 kV line between Bigton and Longworth, producing conditions similar to those originally obtained and avoiding the overloading of the transformer.

This procedure illustrated very simply one of the important uses of the network analyser—that of a tool in the design of power systems.

Harmonics in Power Systems

The purpose of this demonstration was to show how the waveforms in power systems may be distorted by the presence of harmonic frequencies. For this purpose, the ability of the ERA network analyser to produce frequencies from 160 c/s up to 16 000 c/s gives it an advantage possessed by very few analysers in the world, most others being confined to a fixed frequency.

Power supply systems commonly operate at 50 or 60 c/s while radar may operate at frequencies as high as 36 000 Mc/s. By the use of suitable modelling factors any of these frequencies may be represented on ENA. The ideal waveform in power supply networks is that of the sine wave; other shapes may be represented by adding harmonic frequencies to the basic sine wave shape.

To show the appearance of a waveform distorted by a harmonic, a normal 50 c/s wave was first shown on an oscilloscope, followed by a third harmonic wave (150 c/s) and a fifth harmonic (250 c/s), and then the resultant waveforms from the combination of the fundamental and the harmonic frequencies.

The waveform of an electrical power system may be distorted by a variety of causes, and two important pieces of apparatus which cause distortion are transformers and rectifiers.

Figs 5 and 6 show the current waveforms produced by an unloaded 3-phase transformer when it is connected to a power system. Fig 5 shows current waveforms when the neutral of the transformer is connected on the supply side; this waveform contains 3rd, 5th, 7th and higher harmonics. The waveform in Fig 6 shows the result of disconnecting the neutral of the transformer. In this case there is no path for third harmonic current and the lowest harmonic present is the 5th. The current waveform of a loaded three-phase bridge rectifier connected to a power system through a transformer is shown in Fig 7. This contains 5th, 7th and higher harmonics, but no triple harmonics, i.e., 3rd, 6th, 9th, etc.

The second part of the demonstration showed the harmonic voltages produced at a remote point on the network through the operation of a rectifier at a given location. Only the 5th harmonic was used for the demonstration, but all the other relevant harmonics may be studied in the same way.

Finally, it was shown how a filter consisting of an inductance and capacitance in series could be used to reduce harmonic voltages in the system by acting as a short-circuit for particular harmonic currents.

Heat Flow

Heat flow in a medium of uniform conductivity is governed by simple linear relationships which lend themselves readily to mathematical analysis. However, most practical problems of heat flow concern bodies of irregular shape to which awkward temperature conditions may apply, so that mathematical analysis is either difficult or impossible. In such cases the use of an electrical analogue will often greatly simplify the work of analysis and quickly yield a solution.

One of the analogies in common use is that in which temperature is represented by voltage. The thermal quantities and their electrical analogues are shown in Fig 8.

Some of the corresponding thermal and electrical quantities are listed in the table on the next page.

Fig 5. Transformer magnetising current, star-delta connected, neutral earthed

Fig 6. Transformer magnetising current, star-delta connected, neutral not connected

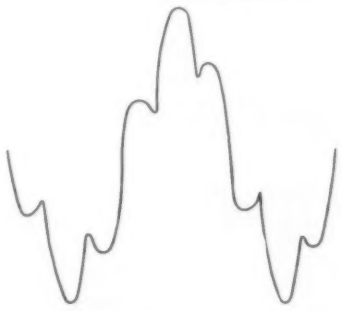


Fig 7. Current drawn by 3-phase bridge-connected rectifier

Thermal		Electrical	
Temperature ...	T	Voltage ...	V
Quantity of heat ...	H	Charge ...	q
Rate of heat flow...	dH/dt	Current ...	I
Capacity	S	Capacitance ...	C
Conductivity ...	K	Conductivity ...	$G=1/R$

As a topical example this demonstration showed the analogy applied to the problem of house heating. A hypothetical two-storey, four-roomed house was considered, all rooms being of equal size.

The circuit diagram of the electrical analogue is given in Fig 9. For simplification, the thermal conductance of the floor of the lower rooms was lumped with that of the outer walls and the thermal capacity of each wall was assumed to be concentrated midway through. Heat loss from each room due to ventilation was represented as thermal conductance, the thermal capacity of the room being that of the air only.

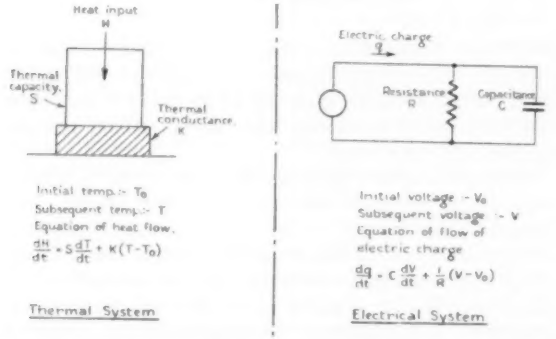


Fig 8. Basis of temperature-voltage analogy for heat flow studies

One of the transient generators of the analyser was used to apply a step-wave of current representing constant heat input to one of the rooms, and the voltage trace on the oscilloscope then represented the rise in temperature of any room as a function of time.

As with most analogues, the component values could be changed at will. To illustrate this, the thermal conductivity of the roof was changed to show the effect of lagging. The increase in the temperature of the rooms for the same heat input was shown on the oscilloscope.

Restriking Voltage

The purpose of this demonstration was to show how the network analyser might be used to find the waveform of the transient voltages which occur across circuit-breakers when interrupting currents in power systems. An example is shown in Fig 10.

When a circuit-breaker operates on an ac power system, the current is normally interrupted as it passes through zero. As a result of the energy stored in the circuit, a voltage is built up across the contacts of the circuit-breaker and may theoretically reach a voltage as high as three times the peak phase-to-neutral voltage of the power system.

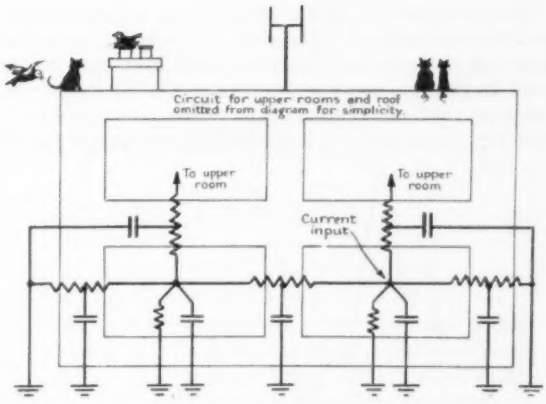


Fig 9. Circuit diagram of the electrical analogue of a hypothetical house

If the voltage across the contacts of the circuit-breaker rises more quickly than the insulating properties of the circuit-breaker, the arc will restrike and if the circuit-breaker is unable to clear the current it will rapidly be destroyed.

In specifying circuit-breakers it is necessary to know the maximum rate-of-rise of restriking voltage to which they will be subjected. There are two problems in finding this rate of rise. One is to know the characteristics of the transformers, lines and other parts of the system, and the other is to make the calculations based on this information.

Information about the power system can only be obtained by making measurements on the system itself or by calculation from known physical dimensions. Calculation of the rate-of-rise using this information can in simple cases be made by mathematical analysis, but where a more complicated system is involved an aid to calculation is necessary. For this purpose the network analyser is the most convenient and flexible means of obtaining the required results.

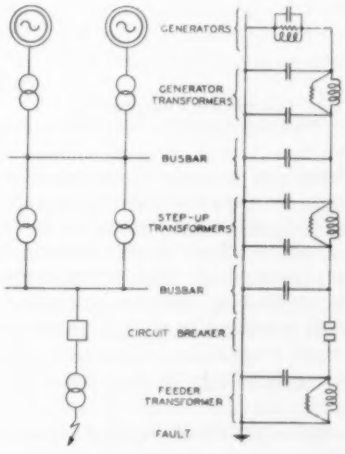


Fig 10. Using the network analyser for studies of re-striking voltage

The left-hand side of Fig 10 shows the arrangement of the various parts of the system. In order to represent these on the network analyser, equivalent circuits are used for transformers and generators. On the right-hand side is an equivalent circuit of the system using the simplified representations. Values have been assigned to the various components based on measurements made on the actual system.

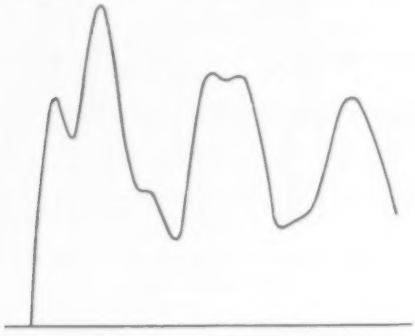


Fig 11. Trace obtained on the analyser CRO, showing the form of the re-striking voltage at the point of the circuit described in the text

A transient generator connected across the part of the circuit representing the circuit-breaker pole will show the form of the restriking voltage at that point. The waveform is that shown in Fig 11. This figure may be compared with Fig 12 which shows a waveform obtained by an investigation on the actual system, and will be seen that the two traces are very similar although not identical. Among reasons for the difference are the facts that it was not possible to make detailed measurements of the generators which were used for this part of the study, and that the capacitances of some of the busbars had to be estimated. These differences would, of course, be shown whatever method of calculation had been employed.

Two further demonstrations showed the representation of a mechanical system by an electrical analogue and how easily measurements could be made by this means,

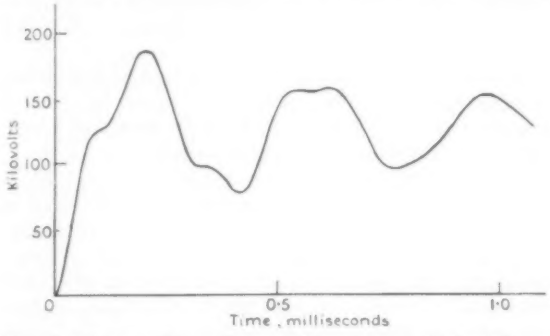


Fig 12. The waveform of re-striking voltage obtained by an investigation of an actual system. This should be compared with the waveform of Fig 11

for which purpose the value of a variable frequency analyser for plotting frequency responses was well shown, and a further example of the use of the analyser for studying mechanical vibrations was shown by an analysis of a simple pendulum.

Some 40 problems have already been solved by ENA in response to requests from members, and further problems will be welcomed for solution on behalf of individual companies. For problems of a routine nature, this service is available at a charge to non-members of the ERA of £40 for a day's occupation of the analyser, including the provision of operating staff and a report of the results. All data and results are regarded as private.

'E 3001' *(Continued from page 5)*

The Alsthom type secondary suspension consists of a vertical column between the underframe and bogie fixed bolster equipped with large rubber conical bearings at each end. Tractive effort is transmitted through the rubber, but fore-and-aft angular movement of the column is controlled by manganese bearing pads, and side movement is controlled by pre-loaded double acting springs. A small proportion of the body weight is taken on 4-coil support springs on each bogie via manganese steel pads.

Under small transverse accelerations, the body oscillates about the lower pivot only, but under the influence of higher forces which are sufficient to overcome the pre-loaded side control springs, the body can move sideways in relation to the bogie. The combined effect is that the period of natural oscillation is governed to a large extent by the severity of the exciting force. It is stated that absence of body roll with this type of suspension is particularly noticeable.

Although the present series of 25 locomotives will be equipped with mercury arc rectifiers as described above, it will be recalled that the AEI organisation has collaborated very closely with British Railways in developing semi-conductor rectifiers for traction purposes*. As a result of this work, 40 locomotives which are now being built in the workshops of British Railways will incorporate AEI germanium rectifiers.

*THE BEAMA JOURNAL, **65**, No 4, pp 151-155

The 21st Anniversary of ASTA

SPEECHES AT THE COMMEMORATIVE DINNER

THIS important milestone in the history of the Association of Short-Circuit Testing Authorities was celebrated by a dinner at the Savoy Hotel, London, on 8 December, 1959—exactly 21 years after the formation of the Association. In the Chair at the dinner was Colonel B H Leeson, CBE, TD, MIEE, who played a leading part in the formation of ASTA and has been Chairman of the Council since 1947.

The guest of honour was Sir Willis Jackson, D SC, D PHIL, DR SC TECH (Zürich), FRS, President of the Institution of Electrical Engineers. Proposing the toast of 'The Association', he referred to some of the better-known achievements of the electrical industry—for example computers, electron microscopes, transistors, guided missiles and nuclear reactors—and then emphasised many other achievements which are no less technically difficult and full of merit but which the general public is inclined to take for granted.

IEE President Praises Industry's Achievements

He instanced particularly some of the things which bear on the assurance of continuity in the supply of electricity; the fact that the thermal efficiency of steam generating stations had increased by something more than 5 per cent during the past ten years or so; that the weight per kVA of turbine generating equipment had decreased by something like 50 per cent in the same period; that the rating of power transformers had increased by a factor of the order of 5, and that the capacity of high-power switchgear had increased by at least this factor.

He then turned to the significance of the example which ASTA had set during the past 21 years in the collaboration between otherwise competing industrial organisations to their mutual benefit, and said he thought it could be claimed as a result of the Association's efforts that this country possessed short-circuit testing facilities which exceeded in their skill and potentialities those possessed by any other country. ASTA, he said, had established a situation in which those facilities could be expanded, both in physical equipment and in manpower, at minimum cost and minimum expenditure of effort when circumstances required.

The close technical and administrative collaboration existing between the ASTA stations had led to the establishment of standards of switchgear performance and the provision of facilities unsurpassed anywhere for the testing of switchgear under circumstances closely akin to those obtaining in practice. He thought he would be correct in saying that many, if not all, of those present at the dinner would welcome an expansion of the collaborative arrangements to other countries besides our own, and in that connection he thought it was very pleasing that there were so many distinguished representatives of the countries of Western Europe present on that occasion.

ASTA's Crusade

Replying to the toast, Colonel Leeson described the book which had been specially produced for the 21st Anniversary as one chapter in the annals of a great crusade in which ASTA, together with the whole of the electrical profession and the whole of the industry, are engaged as one great team. ASTA, he said, could never have done what it had done without the consulting engineers, the supply industry, the National Physical Laboratory, the British Standards Institution, the Electrical Research Association and many others.

The crusade to which he referred was really a crusade to get continuity of electricity supply to industry and to the home with maximum safety, not only to the plant but also to the human lives of those who have to operate it and of the public who consume it, and that crusade is going on, year in and year out.

Colonel Leeson then touched on the beginnings of ASTA and paid warm tributes to the people whose foresight and untiring efforts eventually led to its formation: the late H W Clothier, a director of A Reyrolle & Co Ltd, who did great pioneering work in the development of metal-clad switchgear, and the late E B Wedmore, who was the head of the Electrical Research Station in those days, and both of whom worked hard for the establishment of a testing and proving station; and to Dr Whitney for his fundamental research at the ERA on arc phenomena and air-blast circuit breakers.

Standardisation—National or International?

Then came standardisation, he said, and the problem of whether it should be national or international. They found that the answer was to do both, concurrently and in parallel. The technical coordination in those days between the different testing stations was done in the switchgear technical committee of the BEAMA, of which he was Chairman; they wrote and submitted national specifications for this country, and international recommendations for submission to the IEC.

In this connection, Colonel Leeson paid a tribute to one man in particular for his work as Chairman of Committee No 17 (Switchgear) at the IEC meetings—Professor de Zoeten of KEMA. It resulted within five years in international recommendations in IEC *Publication No 56*, and this was followed by BS 116 which complied with it.

The next step was to establish some authoritative body which would bring about a common interpretation of the standards and uniformity in testing methods adopted by the separately owned testing stations and which could issue authorised certificates of rating. The manufacturers owning the stations naturally turned to the National Physical Laboratory to act in such a capacity. Instead of this, however, there emerged the formation of the ASTA, and the speaker here paid a tribute to Sir Lawrence Bragg, then Director of the NPL, and Sir Frank Smith, then Secretary of the Department of Scientific and Industrial Research, both of whom gave great assistance in bringing the ASTA into being.

After the war much leeway had to be made up in the development of new switchgear to meet demands in this country and in developments for the expanding export trade. Pending completion of extensions to the stations they operated under great stress of work, and many tests for manufacturers without stations which could not be undertaken by ASTA were done at the KEMA in Holland. Colonel Leeson thanked Professor J C Van Staveren for his cooperation and help, and emphasised the closeness of the relations between KEMA and ASTA, through which tests to BS 116 were carried out at KEMA to the same severity as in England.

Looking to the future and the great work that ASTA had still to do, Colonel Leeson went on to say that, as Britain had found it necessary to set up a coordinating body for uniformity of testing at different stations and for authority to issue certificates, and as the same principle applied to KEMA in Holland, it was pretty obvious that other countries would be setting up similar organisations to ASTA. One country had already visited ASTA in this connection, and if other countries were contemplating similar action—as he thought they would be—then the ASTA would be very willing to show their representatives some British stations; to explain how the ASTA was constituted; what it does and why, and to place its experience at the disposal of its visitors.

Promoting International Coordination

He then dealt with the necessary steps to be taken to arrive at the stage where tests done in this country to another country's standard specification would be done in accordance with the interpretation of that country, and vice versa. That seemed to be a common-sense thing at which testing station authorities should aim in connection with European Free Trade and the European Economic Community.

Colonel Leeson said that ASTA was quite prepared to call an international meeting to explore in an informal way what might be done to advance this objective. He had discussed this proposal with Professor de Zoeten, the Chairman of Committee No 17 (Switchgear) of the IEC, and the latter had suggested that a panel of experts drawn from the testing stations should be set up to advise the Committee on possible modifications to IEC *Publication No 56* (*Switchgear*) or on any other steps to advance international standardisation and interpretation.

Colonel Leeson illustrated the need for this by pointing out that modern circuit breakers had such large breaking capacities that they exceeded the testing capacity of any one station. Unit tests or synthetic tests became imperative. The problem was how the tests should be made and interpreted. There was need to get together internationally. It had been done before and it must be done again.

In conclusion, Colonel Leeson said: 'Those who have taken part in the crusade for continuity of electricity supply and safety could join with Shakespeare and say: Out of this nettle danger I have plucked this flower of safety—the ASTA'.

The toast of 'The Guests' was proposed by Mr J R Wilkinson, B SC TECH, MIEE, F AMER IEE, Deputy Chairman of the ASTA Council.

Need for an International Committee of Experts

Professor J C Van Staveren, Managing Director of NV Kema and President of the International Commission for the Approval of Electrical Equipment, responded on behalf of the guests from countries overseas. He emphasised the valuable work of ASTA in promoting international standardisation and uniformity of interpretation of test results, and he fully supported Colonel Leeson's suggestion for promoting uniformity in the interpretation and application of both IEC and national specifications on short-circuit testing.

This, he said, was a matter of great importance. Taking into account the fact that more and more tests are being made on the basis of *Publication No 56* of the IEC, it would be useful if a committee of experts, working within the framework of Technical Committee 17A of the IEC, could make proposals for the details to be observed when performing short-circuit tests in accordance with *Publication No 56*. He recalled that excellent preparatory work had been done by the IEC on a worldwide basis, and by the CEE especially for Europe. He regarded this matter as extremely urgent.

Mr C R King, CBE, COMP IEE, Chairman of the Electricity Council, also replied, mainly on behalf of the guests from this country, but particularly on behalf of the supply side of the industry, which is so dependent on the electrical manufacturers for its safety, its continuity of supply and all that goes with it.

Notes

New ASTA Publication

Rules for the short-circuit testing of circuit-breakers and automatic switches in combination with electric fuses and fuse links have recently been issued in a new publication *ASTA No 22: 1959*.

In November, 1950, *ASTA Publication No 9*: 'Rules for the short-circuit testing of circuit-breakers in combination with back-up fuses' was published as a means of unifying the short-circuit testing of circuit-breakers operating in series with back-up fuses.

Since that time there has been an increase in the variety of switching equipments which operate in series with fuses or fuse links and in which the circuit-breaker or switch operates up to a prescribed limit of over-current, above which the fuse or fuse link takes over the full breaking capacity of the equipment.

In view of these developments, coupled with the experience gained in the short-circuit testing of this type of equipment, *ASTA No 9* has been revised and is now published as *ASTA No 22*. As this new publication also takes into consideration high-voltage automatic fuse switches, it supersedes Supplement No 1 to *ASTA No 8*, which specified tests for switches of this type.

ASTA No 22: 1959 can be obtained from the Association of Short-Circuit Testing Authorities, 36 Kingsway, London, WC2, at 10s 0d.

Duke of Edinburgh Visits an Electrical Engineering Factory

When HRH The Duke of Edinburgh visited the Bedford works of W H Allen Sons & Co Ltd last December the occasion coincided with the beginning of the 80th year of the company's existence.

It was in 1880 that William Henry Allen established an engineering works in London to make centrifugal pumps. This was followed a year later by the manufacture of steam engines to drive the pumps and soon after that the advent of electricity led to the construction of electric generators and the building of complete generating sets for the British Admiralty.

By 1894 the firm had completely outgrown the original works site and it then moved to Bedford, where it now occupies two factories, with another factory at Pershore in Worcestershire specialising in the production of gearing.* It also has another establishment at London Docks which concentrates on marine service and installation work as well as the manufacture of cargo lamp cluster fittings for shipboard use.

Escorted by Mr W Kenneth G Allen, Chairman and Joint Managing Director, and Mr H Norman G Allen, Joint Managing Director, the Duke of Edinburgh began his tour of the works at the Training Centre where he inspected many examples of the work of the apprentices, including working scale models of a diesel engine generating set for a ship's engine room and a steam generating set for industrial power generation.

His Royal Highness next visited the heavy machine shop and the diesel engine erecting shop and test bay, where he saw engines from 100 up to 1 000 hp in course of construction and witnessed the full-scale testing of engines and complete generating sets. From there he went to the electrical shop and the electrical test bay and saw the production and testing of dc generators, alternators, ac and dc motors. The tour also included the large turbine erecting shop with many types of steam and gas turbines under construction, and the steam turbine test bay and the gas turbine test chamber.

Before leaving the works, The Duke of Edinburgh unveiled a commemorative plaque in the main entrance hall recording the Royal visit. This plaque is mounted between two others, one commemorating the 25th year of the reign of HM King George V and his visit to the works with HM Queen Mary in 1918, and the other commemorating the coronation of Their Majesties King George VI and Queen Elizabeth in 1937 and the visit of HRH The Duke of York (later King George VI) to the works in 1920.

An Old Firm Carries On

The old-established firm known until recently as Verity's Ltd will operate in future under the names of Veritys (Maxlume) Ltd and Veritys (Switchgear) Ltd. The name of Verity has been known and respected throughout the electrical industry since the days of Edison and Faraday, and it has recently been purchased by two other equally old-established and well-known electrical firms: William McGeoch & Co Ltd and Osler and Faraday Ltd. It is interesting to note that Veritys were originally established in 1819, McGeochs in 1832 and Oslers in 1850.

Under the new management, the wide range of Verity products are again in production, covering floodlighting equipment, flame-proof fittings, weather-proof fittings, fluorescent lighting equipment, switchgear and control gear specially designed for marine and industrial applications.

Detailed and illustrated catalogues are available from the new Verity companies at Maxlume Works, Aston, Birmingham 6.

An Unusually Large Heating Mantle

The picture on this page shows a giant-sized 'Isomantle' made by Isopad Ltd of Boreham Wood, Herts, who are specialists in this and other forms of industrial heating.

The Isomantle illustrated was used in the works of Glenfield and Kennedy Ltd of Kilmarnock for testing valves with a 60 in (152 cm) bore, 32 of which are being installed in the nuclear power station now under construction by the GEC-Simon Carves Group at Hunterston in Scotland.

The valves are tested at full design pressure while the Isomantle heats them to 800 deg F (427 deg C). This is the operating temperature for the outlet valves; the inlet valves operate at 450 deg F (232 deg C).

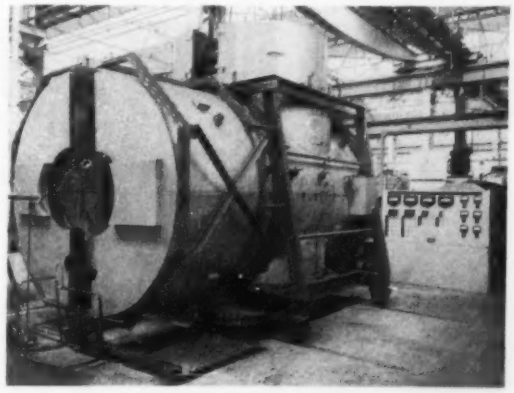
The control panel in the background gives coarse control of each section of the heating mantle by energy regulators, and the high degree of accuracy required for the tests is automatically achieved by additional transistor-operated controls.

Pig Iron from Reclaimed Scrap Steel

An ambitious scheme to produce pig iron used for a wide range of cast iron materials from reclaimed scrap steel has been launched by Ferranti Ltd at their factory at Hollinwood, Manchester. This should result in considerable economies, as the pig iron was previously purchased from an outside service.

The scheme has been made possible by the installation of a new Birlefco 3-ton capacity electric arc furnace, and although the use of such furnaces for the production of steel from scrap metal is quite common today,* the production of pig iron from reclaimed scrap steel is a departure from normal practice. Ferranti Ltd believe that they are the first heavy electrical engineering company in Britain to put such a scheme into operation.

The scrap to be used consists basically of croppings from transformer laminations



The large heating mantle described above, as installed for high-temperature testing of valves for a nuclear power station. In the background is the control panel

* THE BEAMA JOURNAL, 66, No 1, pp 25–26

* THE BEAMA JOURNAL, 66, No 4, pp 129–133

and other mild steel to which will be added back scrap from the foundry together with a recarburising compound. This will bring the carbon from the low figure of about 2 per cent up to the desired 3 to 3·5 per cent and the steel will become cast iron on the addition of silicon and manganese, the amounts depending on the grade of cast iron to be produced.

One of the materials to be produced in the new furnace will be 'Nomag'—a non-magnetic grey cast iron which was developed by Ferranti's Foundry Department in 1923. It also has a high specific resistance and has proved of great value to the electrical industry for the manufacture of resistance grids. Also, because of its non-magnetic properties it is widely used by leading alternator manufacturers in Britain for stator end-plates. It is expected that some 50 tons of this material will be produced monthly in the new furnace.

Spheroidal graphite iron—a newer type of cast iron with the equivalent strength of mild steel—will also be produced in quantities of about 60 tons a month. Spheroidal graphite iron was first developed by the British Cast Iron Research Association in 1948 and has many general engineering applications.

Yet another cast iron to be produced is 'Nodumag', which is basically 'Nomag' with spheroidal graphite and having the same general electrical and non-magnetic properties but a much higher strength.

The Birlefco 3-ton capacity 1 600 kVA furnace consists of a cylindrical, refractory-lined bowl-shaped shell 7 ft (213 cm) in diameter, with 3 triangular-spaced electrodes 8 in (20 cm) in diameter and 6 ft (183 cm) long, projecting vertically through the removable roof and connected by flexible cables to a furnace transformer.

The latter is a 1 600 kVA 3-phase Ferranti transformer with variable reactance to ensure stable operation of the arc over a wide range of furnace secondary voltages from 230 to 95 V and to limit the short-circuit current which would occur if an electrode came into direct contact with the metal charge.

The company states that although it is too early to assess accurately the savings in purchases of pig iron, there is no doubt the furnace will bring about considerable savings in time, money and labour and will greatly assist the Foundry Department to achieve increased productivity.

Another Large Computer Installation

An order has recently been placed with EMI Electronics Ltd by the British Ministry of Pensions and National Insurance for a computer which, when completed, is expected to be one of the largest computer installations in Europe.

The computer will be an all-transistor Emidec 2 400 and will cost over £500 000 to manufacture and install. It will be designed to deal with the huge volume of data processing connected with the new graduated pensions scheme to be introduced in the UK.

It has been calculated that there are some 25 million insured persons, with over a million additions or changes each year. The computer will 'store' full statistics for each insured person, such as name and address, amount of each contribution and the total paid to date. Every day the records of every insured man and woman in the UK will be processed in order to extract information on people reaching retirement age and other changes in their particulars. The computer is capable of completing this task in under four hours.

The Emidec 2 400 will use 17 fast start-stop tape decks and for processing the data in the 'deep store' it will use five 4-in (10 cm) tape decks. A new type of printer capable of producing 3 000 lines a minute will speed the flow of information from the computer. All plug and socket connexions will be gold-plated to achieve complete reliability.

The computer will embody many new features to simplify programming and to facilitate the handling of large volumes of data. Many operations such as input, output and computing can proceed in parallel by means of a time sharing system which makes maximum use of the high speed of the central computer. A versatile programme-interrupt feature allows a large installation with many peripheral units to be automatically programme-controlled.

A 2·6 MW Silicon Rectifier Equipment

In our description of this equipment in our November, 1959, issue* the following statement appeared:

> 'With the exception of the main ac oil circuit-breaker, all the equipment is being supplied by Standard Telephones and Cables Ltd.'

We have since received further information about this installation. The regulation of the entire equipment is effected by an interstage regulator built by Brentford Transformers Ltd, who also supplied the four rectifier transformers supplying the four cubicles into which the complete rectifier equipment is divided.

The stepless on-load voltage regulator controls the input voltage to the rectifier transformers via the constant current control loop, as described in the article in our last issue.

* THE BEAMA JOURNAL, '66, No 4, p 125

Slagging-off operation being carried out on the Birlefco electric arc furnace installed in the foundry of Ferranti Ltd. The furnace control panel can be seen on the right

Trade Publications

Wiring Accessories. The complete range of MK wiring accessories is listed in their new catalogue which covers round and rectangular socket-outlets, cooker control units, appliance switches and switches suitable for mounting in American boxes. *MK Electric Ltd*, Shrubbery Road, London, N 19.

C-core transformers; audio repeaters; numeral indicators. Technical data sheets cover the first two products: MT/103 deals with the rating and dimensions of open C-core transformers and chokes complying with the Joint Services Standards for Radio Components; C/2042 describes a transistor two-wire audio repeater for operation from either a 24 V or 50 V dc supply. Another publication describes the Nodistron—a GN-1 cathode numeral indicator. *Standard Telephones and Cables Ltd*, Connaught House, London, WC 2.

A miniature oscilloscope (Type SO1) is described in a recently issued leaflet. The oscilloscope is designed for use on production line fault finding and by factory maintenance engineers. *Sciaky Electric Welding Machines Ltd*, Falmouth Road, Slough, Bucks.

Telegraph Terminal Equipment. A new publication gives details of a 24 channel frequency modulated VF telegraph terminal equipment. It provides means for establishing up to 24 both-way channels with 120 c/s spacing within the speech-frequency band of 300 to 3 400 c/s. *Telephone Manufacturing Co Ltd, Technical Information Department*, Hollingsworth Works, Martell Road, London, SE 21.

Consumers' service units are featured in a new publication from the Cables Division of AEI Ltd. The units are designed so that all the component parts can be used as separate units or as one composite assembly complete with supply intake chamber and meter. *AEI Ltd (Cables Division)*, 38/39, Upper Thames Street, London, EC 4.

Turbines and Motors are dealt with in the following publications recently received from English Electric: ST/122—steam turbines; MR/111—marine steam turbines; GT/103—gas turbines; DE/217—diesel engines; PS/133—induction motors, and DM/257—high slip, high torque motors. *The English Electric Co Ltd*, Foregate Street Offices, Stafford.

Induction Motors: Some Basic Principles of their Application

H Myers, BEng. AMIEE*

Historical Notes

The induction motor dates from 1889. Tesla exhibited a crude form of 3-phase induction motor at the Frankfurt Exhibition in 1891; Dolivo Dobrowolsky built an induction motor with a distributed stator winding and a cage rotor in 1893 and this was substantially the same as the modern squirrel-cage motor. The slipring rotor was developed at the turn of the century.

Early single-phase motors were of the graduated resistance split phase or repulsion type. The capacitor start and run single-phase motor, although developed, was originally a failure because of the unreliability of capacitors at that time. Advances in radio engineering and the introduction of electrolytic capacitors in the early 1930's brought the capacitor motor to prominence almost to the total exclusion of the split-phase and repulsion motors, except on very small outputs.

Introduction

The popularity of the induction motor is due entirely to its inherent simplicity, which makes it relatively cheap to manufacture, reliable in operation and easy to maintain. This is particularly true of the very common 3-phase induction motor, especially with a squirrel-cage rotor.

* Industrial Machines Department, English Electric Co Ltd

Induction motors are efficient, and although they have a lagging power factor of between 0·85 and 0·95 on full load dependent on the size and speed of the machine, correction equipment can in most cases raise this to higher values when the economics warrant it.

The starting and control equipment for an 'on-off' duty is mechanically and electrically simple, although complicated drives may make the control equipment more complex, particularly for automatic operation.

The 'shunt', or almost constant-speed, characteristic of the induction motor is an advantage for the great majority of industrial drives, but limits its use on haulage work and almost entirely excludes it from traction applications. Special arrangements can be made for varying the speed as described later.

The Fundamental Induction Motor

In order to obtain good efficiency and power factor at full load from an induction motor, a low resistance and low reactance rotor is necessary. Motors designed on the basis of good performance and a temperature rise equivalent to the maximum specified in BS 2613 have torque/speed and current/speed characteristics similar to those shown in Fig 1. The starting torque developed is of the order of 150 per cent full load torque (FLT) with a maximum (stalling) torque of 200–275 per cent FLT, and at full voltage a starting current of about six times full

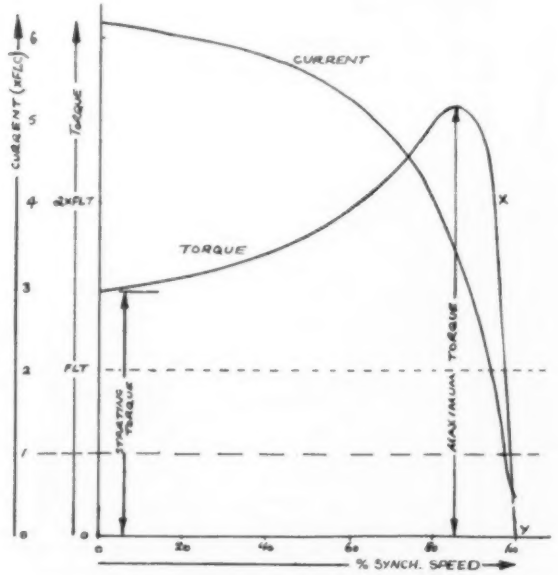


Fig 1. Torque/speed and current/speed characteristics of a typical induction motor of good performance

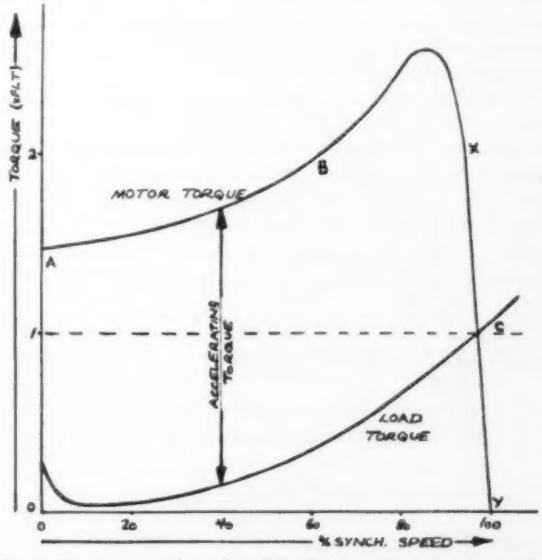


Fig 2. Motor torque/speed and load torque/speed curves of a motor with the torque/speed curve of Fig 1 driving a fan load

load current (FLC). The shunt characteristics are shown by the straight portion (XY) of the torque/speed curve.

In applying this type of motor to a given drive, the load torque/speed curve must be considered, as obviously the starting torque developed by the motor must be greater than that required by the load, and the motor torque must exceed the load torque by a margin sufficient to accelerate the rotor and machinery to its full speed. This point is at the intersection of the motor torque/speed and load torque/speed curves.

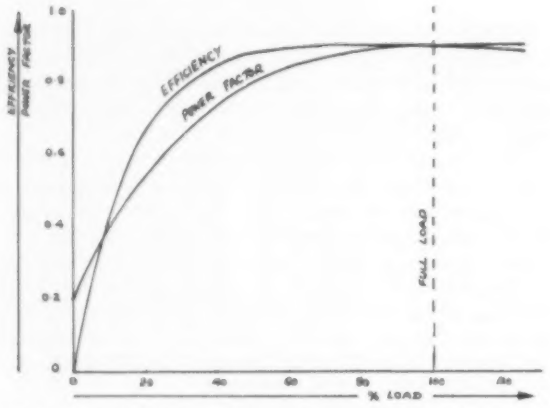


Fig 3. Curves showing the variation of power factor and efficiency with load

Fig 2 illustrates the two curves where a fan load is being driven by a motor having the torque/speed curve of Fig 1. If the point of intersection is in the region AB the motor will crawl, taking a high current. If C is the full load point, then with the intersection in the region BC the motor is overloaded, and with the intersection in the region CY it is underloaded.

Overloading results in overheating which, if sufficiently great, will cause the winding to burn out, and in any case will shorten the 'winding life' of the motor. Conversely, an underloaded motor has both poor power factor and efficiency. Fig 3 illustrates the variation of power factor and efficiency with load.

The difference between the motor torque and load torque during starting is the torque available for the acceleration of the rotor and load. The magnitude of this accelerating torque, the inertia of the rotor and load, and the full speed to be obtained, determine the time required to obtain full speed from start; *ie*, the run-up time of the motor load. A useful but approximate formula for calculating this time is

$$t = \frac{WR^2 \times N}{308 \times T} \text{ secs}$$

where WR^2 = moment of inertia of rotor and load in lb/ft^2

N = full load speed (revs/min)

T = accelerating torque in lb/ft.

or

$$t = \frac{WR^2 \times N}{92.5 \times T} \text{ secs.}$$

where WR^2 is in kg/m^2 and T is in kg/m.

The difficulty is the value of T, which is the average accelerating torque from standstill to full speed. This must be estimated from a diagram such as Fig 2. A better approximation to run-up time can be made by dividing the figure into sections and calculating the times to accelerate through each section from, say, standstill to $N/4$, $N/4$ to $N/2$, $N/2$ to $3N/4$ and $3N/4$ to N, using estimated acceleration torques T_1, T_2, T_3 and T_4 respectively, adding the results together to give total run-up time.

During acceleration the motor is taking a heavy current, and should the period be excessive, the motor will overheat with possible damage to the windings. This time is usually a few seconds, but in some cases 20, 30 or 40 seconds may be permissible; this depends entirely on the design of the machine and the method by which it is started.

The simplest and cheapest method of starting the squirrel-cage motor is by switching direct on to the line. As the initial starting current can be high—perhaps six times FLC of the motor or even more—the method is limited to small machines unless the power supply system can withstand this high starting current.

By applying a reduced voltage across the motor terminals until the motor is almost up to speed, the starting current can be reduced, but the starting torque and accelerating torque are also reduced.

The most common method of reduced-voltage starting is that which connects the stator windings in star across the supply volts until the motor is almost up to speed and then, by switching, reconnects the windings in delta. The voltage applied per phase (in star) is therefore $1/\sqrt{3}$ the value of the running (or delta connected) voltage. Thus the starting torque and starting current should be reduced to one-third of their full voltage values, but leakage reactance increases at the reduced voltage, causing the actual values to be between one quarter and one third of the full voltage values. The effect is as seen in Fig 4.

The other types of reduced voltage starting are auto-transformer, primary resistance and reactance, which are

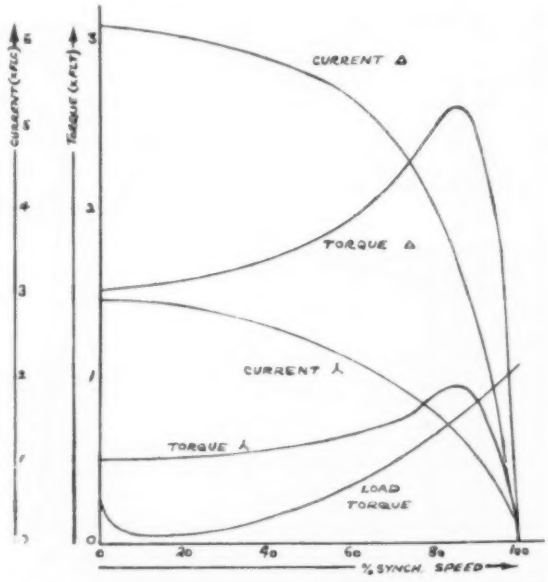


Fig 4. Curves of starting current and starting torque for star-delta starting

all variations on the main theme. The autotransformer has several tappings at 50, 65 or 85 per cent of the line voltage, which gives something less than 25, 42 and 64 per cent of the full-voltage values for both current and torque.

When considering the use of a squirrel-cage motor for a particular drive there are two main factors to be taken into consideration: the required starting torque coupled with run-up time, and the permissible starting current. If the various methods of starting and the low resistance, low reactance rotor do not give the required characteristics, other types of rotors must be considered.

Effect of Rotor Design on Speed/Torque Characteristics

If a lower starting current is required, a higher reactance rotor can be used which reduces the starting current to the order of five times FLC. This is obtained at the expense of the power factor, which will not be as good as the low resistance, low reactance rotor.

Alternatively a high starting torque of some 300 per cent FLT may be desirable, and this can be achieved by the use of a high-resistance type rotor. This is useful on frequent starting and reversing drives where high acceleration and short run-up time is wanted. The higher rotor resistance reduces the efficiency slightly and also produces a higher value of slip at full load. Such high slip motors are often short-time rated, and are widely used with flywheel drives to smooth fluctuating loads.

An increase in starting torque and a reduction in starting current can be obtained from the Boucherot or double-cage rotor. Starting torques of 200 per cent FLT or more and starting currents of 4·5, 5 or 6 times FLC are common with this type of rotor, but generally it should not be used for high-inertia loads, as only short run-up times are possible owing to the danger of burning out the starting cage of the double-cage winding.

Figs 5, 6 and 7 compare the speed/torque curves of these three types of rotor with the low resistance, low reactance rotor. The curves marked 'a' refer to a low resistance, low reactance rotor; 'b' to a low resistance, high reactance rotor; 'c' to a high resistance, low reactance rotor and 'd' to a double-cage rotor.

If the required current and torque relationship cannot

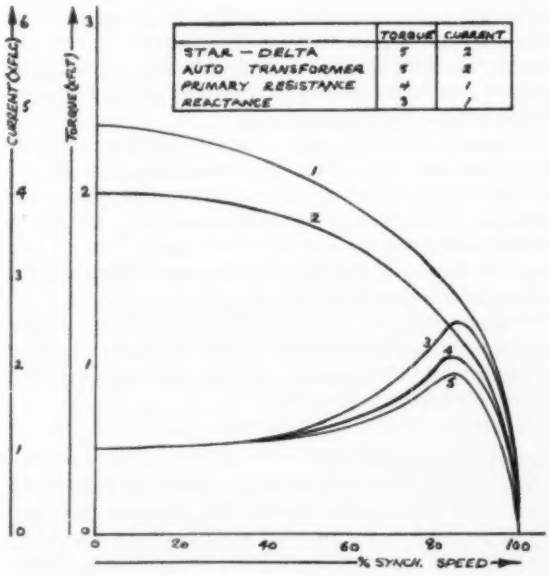


Fig 5

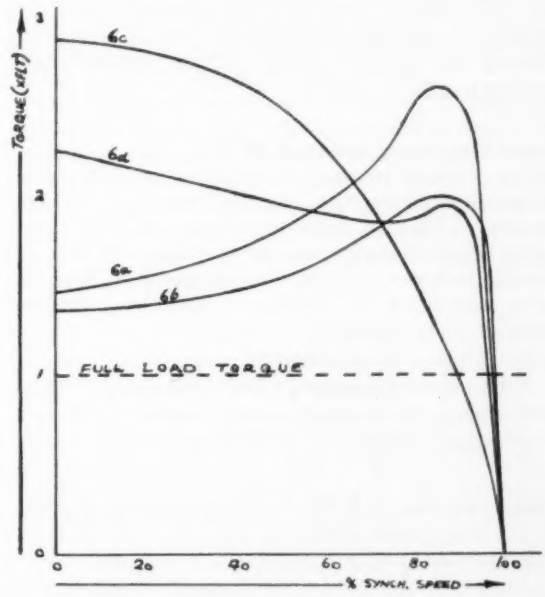


Fig 6

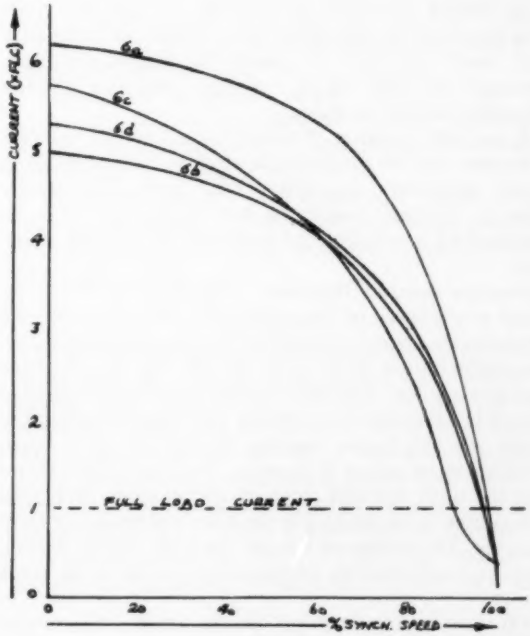


Fig 7.

These three curves show the effect of rotor design on speed/torque characteristics as explained in the text

be obtained from these designs then a clutch, fluid flywheel or similar mechanism must be used to allow the motor to run up to speed before the load is applied. Alternatively a slipring motor can be provided.

The slip-ring motor has a wound rotor of the low resistance, low reactance type; additional resistance can be included in the rotor circuit by making connection through the slip-rings. This is an effective way of varying the rotor circuit resistance and therefore the torque available at different speeds. It also provides a means of limiting the starting current, and yet obtains a high starting torque.

Speed Variation of Induction Motors

In the ordinary induction motor the speed falls steadily from near synchronism at light load to a slip of one to five per cent at full load, dependent on the size of the motor. Generally the larger the machine the smaller the slip; also the slip increases with the rotor temperature. When the drive necessitates a variation in speed, the principal methods make use of:

1. Change of rotor resistance.
2. Change of frequency applied to the stator.
3. Change of poles in the stator winding.
4. Change of frequency in the rotor.

Speed Variation by Rotor Resistance: Slipring Motors

It has been shown previously that the rotor resistance influences the speed/torque characteristic, and variation of rotor resistance can be used to adapt the speed to the torque. If resistance is permanently inserted in the rotor circuit, the slip on full load will be increased. The heat produced in the resistance may be considerable and must be dissipated; thus it is not desirable to build the rotor with the required resistance, but to build the rotor with only small resistance and insert the desired resistance externally in the circuit, so that adequate cooling arrangements can be made.

A variable speed is obtained by a variable external resistance, and the smoothest control is obtained by using liquid resistances; moreover, their tanks will greatly assist in cooling. Automatic control of speed can be obtained by servo-powered variation of external resistance.

Ventilation—and therefore cooling as well—are reduced as the speed of the motor falls. To ensure that the insulation temperature remains within permitted limits, the machine must be derated and the size of a machine for a given output must therefore be increased. If constant torque is demanded, the greater the speed reduction the larger will the motor become. In the rare cases when constant horse power is required, the torque (and therefore the rotor current) increases as the speed decreases, thus producing more heat in the rotor and requiring more derating. The maximum torque available from a slipring motor is unaffected by change of resistance in the rotor circuit.

On fan and centrifugal pump loads, the torque decreases with the square of the speed. The decrease in rotor current is more rapid than the decrease in motor cooling and overheating will not occur; a larger machine is not therefore necessary.

Speed Control by Frequency Variation

Relationship between frequency and speed is given by

$$f = n \times p$$

Where f = frequency, n = revs per sec and p = pairs of poles.

Frequency variation provides a simple and effective method of varying speed, provided that a variable frequency supply is available.

Speed Control by Pole Changing

In this case, the speed variation is limited to a series of definite speeds. If a speed ratio of 2 : 1 is required a tapped winding can be employed, but for a third speed of a different ratio another separate winding must usually be provided. To accommodate two windings in a machine the size must be increased.

For example, a 4/8 pole tapped winding will give two speeds with one winding, the change in winding connections being made by a suitable switch. With 4/6 poles two windings are necessary, but 4/6/8 poles can be accommodated with two windings, one tapped. By tapping both windings 4/6/8/12 poles can be obtained, giving four speeds.

It is possible to accommodate a 3 : 1 speed ratio from one special tapped winding. The design difficulty here is obtaining a suitable winding which will give satisfactory run-up torque on the slow speeds and will not be prone to cogging.

When switching from a high speed to a low speed, a time delay or choke should be incorporated in the system to prevent excessive braking torques.

Speed Control by Cascade Connection

For this, two slipring induction motors are mechanically connected together. In one machine the slip is considerable and the emf generated in its wound rotor is fed into the stator of the second machine. By using two machines with different numbers of poles, various speeds are obtainable, individually and in cascade. The synchronous speed of the combination corresponds to the total number of poles of the two machines.

The power output is shared between the two machines in the ratio of their poles. The second machine derives its input from the first machine, the rating of which must therefore include that of the second machine. The losses in this machine cause a lower total output than for one machine alone and the addition of a second magnetising current lowers the overall power factor.

Pole changing can, of course, be combined with cascading to give a greater selection of speeds. However, these methods—probably because of the reasons described above—find little application.

Motors Running in Step

It is possible to ensure that two motors wound for the same speed run together in step. This is done by connecting their sliprings to a common resistance. The circulating current in the two rotors provides a synchronising torque, and the two machines will pull into step and run together. The motors are run up to speed by reducing the resistance, as in normal starting of slip-ring motors, but a small amount (about 10 per cent) of the resistance is left in the

circuit to maintain a synchronising torque. The drive and transmission must be sufficiently flexible to allow any displacement between the two loads to be corrected so that the motors pull into step and run together.

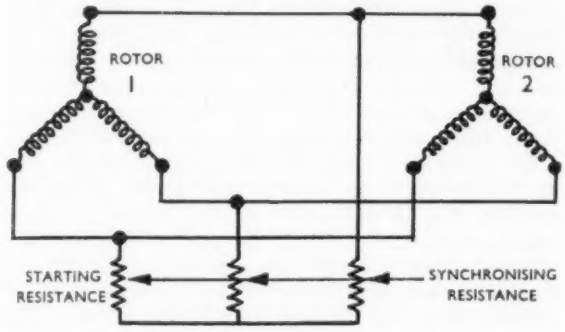


Fig 8. Circuit arrangement for two motors wound to the same speed and running together in step

Synchronous Induction Motors

A synchronous induction motor combines the advantages of the slip-ring motor starting characteristics with the power factor correction ability of the salient-pole synchronous motor.

This is a very useful form of ac motor because it can perform both a mechanical and an electrical duty. It can be used as a driving motor (often driving a ventilation fan) in the plant, and will also correct the power factor of the total load current taken by the plant. It is a matter of economics whether the reduction in chargeable electrical consumption offsets the additional cost of employing a synchronous motor to perform the mechanical duty.

In effect, the machine is a slip-ring induction motor and is run up to full load speed as such. A suitable direct current is injected through the slip-ring and the magnetic field produced in the rotor locks into step with the rotating field in the stator, making the rotor revolve at synchronous speed. The dc supply is usually taken from an overhung dc exciter mounted at the non-driving end of the machine.

For a given load there is a minimum dc excitation necessary to pull the rotor into synchronism. When in synchronism this excitation can be increased or decreased. If it is decreased, a lagging exciting current is drawn from the ac mains, but with an increase of direct current the current from the line becomes leading, so that stator reaction can neutralise this excess of field in the rotors. If the excitation is maintained constant and the load is varied, then with decrease of load the power factor becomes more leading, and vice versa.

Should the torque demand upon the rotor exceed the maximum, the rotor will drop out of synchronism. The machine is now an induction motor and can produce a much greater torque. The torque which pulls the machine out of synchronism is called the pull-out torque, and the maximum torque of the induction motor is called the stalling torque. Pull-out torque is usually between 140 and 200 per cent of full-load torque.

SOME SPECIAL APPLICATIONS

Chemical Works Motors

Motors with special features have been developed for chemical works duties where corrosion or explosive atmospheres (or both) are encountered.

Non-Flameproof Situations

The site conditions may be mildly or highly corrosive and chemical works motors have been developed to resist corrosion. The following special features have been embodied by one leading manufacturer in its range of BS dimensioned totally-enclosed fan-cooled motors, thus retaining the advantage of standardisation.

The fan is phenol-formaldelyde instead of aluminium alloy and the rating plate is plastic instead of brass. Cast iron is more resistant to corrosion than sheet steel and so the sheet steel fan cowl is replaced by one of cast iron. Special attention is given to the windings as they are susceptible to attack. Four impregnations are given to them, and have been found to increase greatly their resistance to corrosion.

Flameproof Situations

In the UK, the Factories Act requires that for inflammable sites Buxton certified motors must be used*. A flameproof motor is one that will withstand, without injury, any explosion of the prescribed flammable gas that may occur within it under practical conditions of operation within its rating, and that will prevent the transmission of a flame such as will ignite the prescribed gases present in the surrounding atmosphere.

The situations are divided into four groups according to the gases or vapours present. Group IV is the most hazardous; the gases in this group are acetylene, carbon disulphide, hydrogen, and water gas. For groups I, II and III, maximum allowable dimensions for joint gaps and other openings in the enclosure are specified in BS 229 for these gas groups. The electrical specification for flameproof motors is BS 741.

Flameproof induction motors have so far been constructed for, and have obtained, the Buxton Certificate for groups I, II or III. As yet no machine has been awarded a certificate for Group IV hazards.

The salient features of a flameproof motor are: (a) rugged construction and (b) machined flanges and joints of the correct clearances to comply with the certification of flameproofness.

Purged Motors

In this design, a totally enclosed motor is fed with air or an inert gas at a pressure greater than that of its surroundings. This avoids the risk of an explosion occurring inside the machine, as the explosive gases cannot enter against the excess internal pressure. A pressure switch is incorporated to ensure that, should the pressure within the motor fall below that of its surrounding atmosphere, the supply is automatically tripped.

A nitrogen-purged 25 hp 75 rev/min motor was recently manufactured to drive the agitator in a nylon

* This is a certificate issued by the Mines Department Testing Station at Buxton, under the authority of the British Ministry of Power. Apparatus so certified must carry an indication of the certificate number, the group of gases for which certified, and the distinctive registered mark 'FLP' granted under licence to the manufacturer.

manufacturing plant which contained a highly inflammable liquid at a pressure of approximately 120 lb/in² (8·4 kg/cm²). The space above the liquid was occupied by steam and nitrogen.

Normal drive through gearing and glands round the agitator shaft involved a considerable and also a costly leakage. It was decided to make the motor as a part of the pressure vessel and to purge it with nitrogen at 125–130 lb/in² (8·8–9·14 kg/cm²). Gearing was eliminated by adopting a 16-pole winding and a supply frequency of 10 c/s at 350 V. As the vapour was highly corrosive the motor frame, end brackets and shaft were made of stainless steel. The weight for this 25 hp motor was 1 350 lb (612 kg). Leakage was thus prevented, and because of the greater pressure in the motor, the corrosive vapour could not enter it. Both motor and terminal box were purged with nitrogen.

Canned Motors

General Description

The development of these motors is the outcome of the utilisation of nuclear energy, although in a simple form they have been used for submersible pumps. In many nuclear power plants, the heat generated by atomic fission is transferred to a pumped liquid in a hermetically sealed system.

Because this liquid is at a high temperature and pressure and may be radioactive, the pumping difficulties are considerable. Because of radioactivity, the minutest leak must be avoided and thus the normal shaft seal between motor and pumps had to be eliminated by placing both in a single pressure-tight housing. Thus the pumped fluid has access to the bearings and the space between rotor and stator. Conventional oil lubrication cannot be employed, and so the pumped fluid is used as the lubricant. The bearing materials must therefore be extremely good, corrosion resistant, and compatible with the pumped fluid. The use of carbon bearings with the bearing surface of the shaft hardened, is one method.

The stator windings are protected from attack by lining the stator bore with a thin hollow cylinder of a non-magnetic corrosion-resistant material. The squirrel-cage rotor is protected similarly. These 'cans' are welded leak-tight in position and have led to the term 'canned motor'.

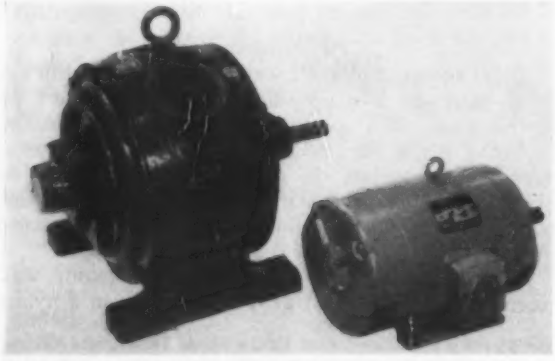


Fig 9. Two 3 hp, 8-pole protected type squirrel cage induction motors, but 50 years apart. A 1908 Siemens motor weighing 352 lb (160 kg) compared with a modern C type motor with class E insulation weighing 145 lb (66 kg)

The stator shell and stator terminals must be capable of withstanding the fluid pressure if the stator can should rupture.

A restriction is placed between pump and motor which creates a 'backwater' from the main flow. Because the pressure on each side of this restriction is the same, there is only a slight eddying of the fluid and no positive flow. The fluid in the motor is circulated through a heat exchanger and additional cooling is provided for the stator core and windings. This enables the temperature of the motor to be reduced below that of the pumped fluid and thus a heat barrier is necessary between pump and motor.

The pump itself is of the centrifugal type, overhung on the motor shaft. In nuclear applications where the pumped fluid is radioactive to some degree, hermetic sealing of the entire unit into the pipe work is essential.

High-temperature-resisting insulating materials can be used to meet particular temperature conditions of the pumped fluid, and the heat exchanger can reduce the motor fluid temperature to an acceptable level.

Performance

There are two main sources of heat within the motor, and the energy from them is removed by the external supply of cooling water. Rotor electrical loss, the fluid friction loss produced by rotation, the major part of the stator can eddy losses, and heat leaking through the thermal barrier form one group, the combined heat eventually appearing in the rotor space fluid. The second group combines the remainder of the can eddy loss, the stator iron and copper losses, and the heat from the pump volute conducted through the motor structure to the stator barrel. This heat is transferred to the external cooling water.

It is thus apparent that the losses of these units will be far greater than those in a conventional motor and pump. If a liquid is pumped, the rotor friction losses are heavy. The cans virtually form a short-circuited turn, causing a considerable 'can loss', and the thickness of the cans greatly increases the 'air gap' between rotor and stator. These factors reduce the motor efficiency and the power factor.

To reduce the rotor friction horsepower to a minimum, the diameter of the rotor is kept as small as possible. This results in a large length-to-diameter ratio.

Applications

These units are costly and can only be justified economically where conventional motor pumping is impossible, or where maintenance is difficult or expensive.

So far as the author is aware, they have up to now only been used in nuclear power stations, having been developed in the USA for the purpose of pumping water or liquid metal coolants. The difficulties of liquid-metal pumping are the cold trapping and mass transfer problems arising if the liquid is cooled in the motor space in order to maintain acceptable temperatures for the electrical insulation.

These seem to be the possible solutions:

(a) Cool the liquid in the motor space and continuously filter it to remove any trapped oxides.

(b) Design a motor with thermal barriers, and cool the windings instead of the liquid.

Other problems in the pumping of liquid metal are the preheating and draining of the circuit.

Units have been built in America with outputs approaching 2 000 hp and capable of producing system pressures up to 3 000 or 4 000 lb/in² (210 or 281 kg/cm²). Possible applications are in the pumping of alcohol, petrol, liquid fuel, volatile liquids, acids and poisons, liquid gases, perfume concentrates, liquid food, and boiler feed water.

Wet Stator Units

These are motor pump units and, as with canned motors, the pumped fluid circulates in the bearings and rotor gap, but there are no cans in the stator bore and thus the fluid is allowed to contact the stator windings.

These units have been manufactured in the UK for some time. They have been used for pumping boiler feed water in conventional power stations and for special applications.

Wet stator units have the advantage over the canned unit in being slightly more efficient and less costly, but with the disadvantage that they are more limited in application, as the winding insulation must withstand contact with the pumped fluid.

Electro-Magnetic Pumps

These are used for the pumping of liquid metals which are electrically conducting. Although strictly speaking they are not induction motors, their basic principle is the same.

Alternating Current Electro-Magnetic Pumps

The pump has a flat stator which contains a polyphase distributed winding in slots in a laminated core. The currents in this winding produce a linear travelling magnetic field. A column of the conducting liquid lies in a duct across the face of the core. Voltages are induced in the fluid and currents are created, resulting in a force along the duct. The integrated effect of this force along the duct is the pressure of the pump. (See Fig 10.)

Two flat stators are placed on opposite sides of a layer of conducting fluid (usually sodium or sodium/potassium) and so connected as to produce additive magnetic fields. The pump duct forms the primary enclosure and contains no working parts or seals. The secondary structure consists of the magnetic circuit and electrical windings, and is filled with an inert gas during operation. This prevents the sodium reaching the outside air in the event of a primary leak.

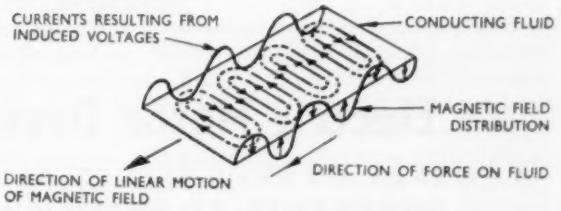

CURRENTS RESULTING FROM INDUCED VOLTAGES
CONDUCTING FLUID
MAGNETIC FIELD DISTRIBUTION
DIRECTION OF FORCE ON FLUID
DIRECTION OF LINEAR MOTION OF MAGNETIC FIELD

Fig 10. Illustrating the principle of the ac electro-magnetic pump

In order to remove heat from the stator, the assembly has cooling water circulated through it and has copper laminations inserted between several laminations of electrical steel to increase thermal conductivity. The windings are insulated with glass and mica. Expansion joints are necessary to permit differential expansion between pump and casing. A heat barrier is placed between duct and stator surface. The power factor is low —of the order of 0·4—but the efficiency may reach about 50 per cent.

Direct Current Electro-Magnetic Pumps

It is possible, of course, to make an electro-magnetic pump to operate on dc. For example, a very high current —some 250 000 A, 2·5 V—produces a dc field perpendicular to the liquid metal and creates a force sufficient to deliver several thousand gallons a minute against a pressure head of a few hundred feet.

Conclusion

As the purpose of an induction motor is to drive, this article has attempted to describe (a) the output characteristics and the means by which they can be varied, and (b) by selecting a few examples, the developments made to fit a motor to its environment. It is hoped that the latter illustrate the ingenuity of the British electrical industry and some of the problems it is being called upon to face.

Acknowledgments

The author wishes to thank the Sales Manager and Chief Engineer of the Industrial Machines Department, English Electric Co Ltd, and colleagues who have assisted in the preparation of this paper.

REFERENCES

1. Blythe, R W, 'Chemical Works Motors', *Corrosion Prevention and Control*. Nov, 1958 and Jan, 1959.
2. Seim, O S and Jaross, R A, '5 000 gal/min Electromagnetic and Mechanical Pumps for the ERB II Sodium System', *ASME*, March, 1957 (57 NESC 94).
3. Erwin, A F, 'Pumps for Nuclear Power Plants', *ASME*, March, 1957 (57 NESC 98).
4. Watt, D A, *Journal IEE*, April, 1959.
5. Fenemore, A S, 'Linear Induction Pumps for Liquid Metals', *The Engineer*, May, 1957.

Electric Motor Development and the User

A SURVEY OF PROGRESS IN AC MOTOR DESIGN WITH PARTICULAR REFERENCE TO BRITISH AND AMERICAN STANDARDS

C V Hill, BEng, AMIEE*

ELECTRIC motors in the United Kingdom are built to BSI performance standards prepared with the help of the manufacturers and representative users. There are many motor users well qualified to express their own opinions effectively and thereby to influence the trend of design. When changes are made, however, it is the general body of users who must ultimately be satisfied, since they have a practical outlook and may not even be interested in the theoretical considerations that lie behind the proposed changes. There must be interpretation in terms that appeal to users and their views must be collected and conveyed to the proper authorities. These duties often fall to the technical Press and the sales engineers of manufacturers.

The present is a period of considerable development, affecting all classes of motor to some extent and, in particular, the general purpose ac motor. It is in this case that interpretation is most required, rather than in that of the larger 'tailor-made' machines where manufacturer and purchaser are in close contact with one another. It is therefore proposed in this article to consider recent developments as they affect the general purpose motor. As a preliminary it is desirable to sketch in some of the background details by referring to the general trends and problems of modern development.

Changes in British Standards

The induction motor has been in use for more than 60 years (some early examples are illustrated in Figs 1 to 4), and as the simplest and most widely used motor it might reasonably be assumed that stability in design and construction would have been reached. This is true only to the extent that further serious progress now depends upon the possibility of altering the long-established technical standards in certain important respects.

Since the war there has been a number of significant changes in British Standards. Thus a single standard BS 2613 : 1955 was issued combining the contents of BS 168, BS 169, BS 225, and BS 226, and this has been reissued as BS 2613 : 1957. Furthermore, a rating and dimensional standard—BS 2083 : 1954—was established for TEFC squirrel cage motors of 1 to 25 hp, followed by BS 2960 for ventilated motors with Class 'E' insulation in the range 1 to 50 hp. It appears likely that Class 'E' insulated TEFC motors in the same range of horse-powers will shortly be covered, with possible extension to larger outputs.

As a first reaction, users may ask why so many important changes should be needed in a comparatively short period and, indeed, why such changes are needed at all. It must be recognised that pressure always exists to seek out new and better materials leading to smaller machines.

One reason is a continued increase in cost. Thus in the 20 years bridging the last war the cost of motor production more than trebled. Another reason is that the methods of utilising motors have changed over the years. The emphasis has moved from group-driving, with motors mounted in an annexe or on a wall bracket, to individual driving with the motors alongside, on top of, or even inside the driven machinery.

Publicity is sometimes given to early machines of heavy construction capable of enormous overloads and practically indestructible in onerous working conditions. Such motors would now prove wasteful of material and too expensive to buy. Furthermore, they would almost certainly be too large for the space available. To a large extent the more compact the motor can be made, the greater will be its range of application.

A further effect of the above development is a lowering in the average horse-power output required for industrial drives. The majority of general purpose motors are to be found in the range 1 to 50 hp, and the optimum output is of the order of 3 to 5 hp. Many earlier motors were either of the slip-ring type or, if of squirrel cage construction, they had to be started on reduced voltage and with the load removed by means of a clutch or fast-and-loose pulley. Nowadays a large proportion of general purpose industrial motors are squirrel-cage machines starting on full voltage and capable of accelerating the driven machines against their full load torque, and this change has considerably enlarged the scope of this simple type of motor.

It is thus evident that the design of motors cannot

Fig 1. Induction motor of about 1905 showing open skeleton frame construction

* Industrial Machines Department, Motor and Control Gear Division, Associated Electrical Industries Ltd.

stand still, although in special circumstances—such as wartime—the process of development may be suspended. Technical development has always proceeded in a series of steps. Thus a recent American book shows how a particular size of induction motor which, 50 years ago, had an output of 7·5 hp, has been up-rated at approximately ten year intervals until it now gives 40 hp. This is perhaps an extreme example of a process that is characteristic of the induction motor throughout the years.

Towards a Smaller Machine

Accepting these trends, the course of development should next be considered. Those familiar with the progress of British motors over a sufficient period will recollect that prior to 1910 they were of open skeleton frame construction with heavy sleeve bearing endshields. A large saving in weight was made during the next decade by introducing a box type frame and bell end brackets. Even more impressive economies resulted, in the 1920s, from replacing sleeve bearings with ball and roller bearings, starting with the smaller machines and gradually extending the change upwards.

Weight saving in very large motors was achieved by introducing fabricated steel construction for frames, end-brackets, baseplates, and even for such items as pedestal bearings. It will be realised that this trend towards lighter machines was only one aspect of development and takes no account of the many details where improvement has been made as a result of research and experience. When new machines were introduced weight saving was not always the object. For example, Fig 6 illustrates a line of machines developed to provide interchangeable main and fixing dimensions with corresponding ac and dc motors.

Between 1920 and 1930 the tendency was again towards the smaller machine and this was achieved by exploiting new magnetic materials and methods of cooling. Thus Fig 7 illustrates one size of a range of radially-ventilated induction motors extending to about 50 hp. For larger outputs this particular manufacturer produced a range of motors axially-ventilated by a special high air velocity cooling system. Most British firms had their own schemes of progressive development until a stage was reached where the possibilities of the available materials appeared to have been exhausted.

The Thermal Rating

Before the last war some attention had been paid to differences in thermal rating methods for ventilated motors between British, Continental and American practice. After the war there was a strong suggestion from large users, supported by the manufacturers, that the apparent selling advantages that these methods gave to Continental machines should be removed. Since thermal rating is the basis of the British performance standard, this request was a plea for changes in these standards, and after considerable discussion this led to the issuing of BS 2613 : 1955.

When motors to this British Standard reached the market it became necessary to know, as a matter of practical application, how they differed from previous motors built to BS 168 and what was involved in the terms CMR (Continuous Maximum Rated) and CRPO (Continuous Rating Permitting Overloads). The differences may be indicated briefly as follows.

The main purpose of a thermal standard is to ensure a satisfactory working life for motors using classified insulating materials, and this depends upon keeping within the temperature limits set by international agreement. The most widely recognised insulation for general purpose medium voltage motors has hitherto been Class 'A'—covering impregnated organic materials and enamelled wire. The limiting temperature for Class 'A' material is 105 deg C, above which the insulation life is considerably reduced. The maximum temperature usually occurs at some 'hot-spot' within the windings inaccessible to a thermometer, and some allowance has therefore to be made for the fall in temperature between this hot-spot and the point of measurement. For ventilated machines this allowance is of the order of 10 deg to 15 deg C. With the latter figure the measurable temperature limit is 90 deg C. Assuming overload working, BS 168 allowed a maximum ambient air temperature of 35 deg C and thus the difference of 55 deg C was available as the working temperature rise of the machine.

The meaning of the various classes of rating can be seen from Fig 5. In this diagram the curve represents some assumed relationship between continuous horse-power output and temperature rise for a particular machine. The output *X* for 55 deg C is CMR (Continuous Maximum Rating). If it were decided to stamp rating *Y* on the nameplate and to keep the available output in the

Fig 2. Early 1920 induction motor showing transition to box-type frame

Fig 3. Box-type frame for outputs up to 5 hp

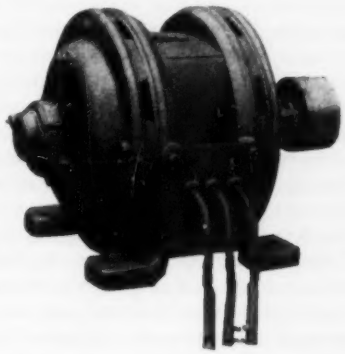


Fig 4. Riveted frame motor for outputs up to 5 hp

region between 40 deg and 55 deg C for possible overload working, then the basis of rating would be CRPO (Continuous Rating Permitting Overloads).

The form in which the overloads were stated distinguished British practice from the American. In BS 168 it was laid down that the additional output beyond point *Y* should be stated as an intermittent overload of 25 per cent to be carried for a period depending on the particular range of output considered: for example, for 10 hp,

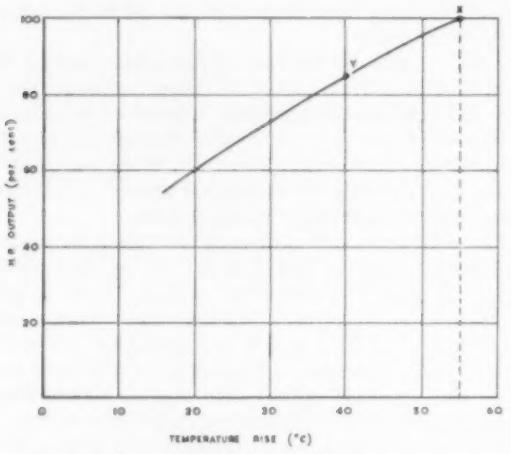


Fig 5. Relationship between continuous output and temperature rise

1 000 rev/min and upwards, this period was two hours. In the American equivalent, the excess of rating *X* over *Y* was stated as a service factor applicable to rating *Y*. Thus a service factor of 15 per cent means that, in addition to the continuous 40 deg C rating *Y*, the machine will carry a further 15 per cent more horse-power continuously without undue heating. It is seen that a change from CRPO to CMR might involve an increase in nameplate stamping of say 15 per cent without changing the machine in any other respect. This would mean that the maximum torque performance expressed in absolute terms (lb/ft) would be unaltered, but expressed in terms of the new Continuous Rating (times full-load torque), it would vary inversely as the horse-power.

A complete increase in rating would require that the maximum torque should remain unchanged in terms of the new full-load torque, which would mean increasing the magnetic flux as the square root of the horse-power. In the general case such a change might well involve some fundamental changes in motor design.

The adoption of CMR is now generally accepted, but when the change was first made in BS 2613 : 1955, motors of 50 hp per 1 000 rev/min and below were retained for a period on CRPO until the issue of BS 2613 : 1957, when a complete change to CMR was made. It is instructive to recall the reasons for this interim period.

It has become customary to build general purpose motors in a series of preferred outputs so that adequate stocks of finished machines may be available, and these proceed by steps such as those of BS 2613 Clause 11. A 5 hp ventilated CRPO motor might be re-rated to, say, 5·8 hp on a CMR basis, but this new rating does not fit into the 'preferred rating' series and thus does not 'save a frame size'. Alternatively, the rating might be retained at 5 hp and a reduction made in the active material employed, but in this latter case the saving in cost would not be held to compensate for the loss of the sustained overload capacity and higher working temperature. A change to CMR alone would be inadequate in this range of outputs to secure a reasonable cost saving, but if some other means of increasing the rating were available, the combined effect with a change to CMR might achieve the required results. Such a possibility occurred with the introduction of Class 'E' insulation capable of working at a higher temperature rise than the previous Standard Class 'A' insulation covered by BS 168. Class 'E' is now generally accepted, but in order to preserve the sequence of events it is now necessary to refer to the development of British Standard Dimension motors.

Introduction of British Standard Dimensions

At the close of the war the Government appointed the 'Lemon Committee' on Standardisation in Industry to see if the variety of engineering products could be reduced by standardisation in the interests of productivity and economy. As a result of this Committee's consultations with the electrical manufacturers, the latter appointed in July, 1937, their own Investigating Committee to consider the standardisation of motor dimensions.

In due course proposals were submitted to the British Standards Institution which led to a dimensional standard BS 2083, which established horse-power assignments and main fixing dimensions for a range of totally enclosed fan cooled, Class 'A' insulation, squirrel cage motors of 1 to 20 hp at speeds of 750 to 3 000 rev/min and which were electrically to the requirements of BS 168. The constructional details of the machines—such as core dimensions, winding particulars and so on—were in accordance with the individual manufacturers' own practice.

Processes of standardisation are bound to arouse some controversy. The advantage to the user in mechanical interchangeability between various makes of motor is immediately obvious, although on a short term basis, both manufacturer and user must submit to the inconveniences of discarding their previous arrangements in favour of the new National Standard.

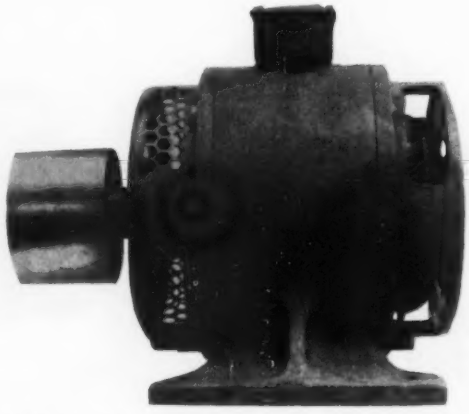


Fig 6. Motor of a range providing interchangeable main and fixing dimensions for ac and dc machines

Certain dangers also exist that are not always easy to guard against because they may not be obvious, and it is possible that standardisation may tend to crystallize design. Once the dimensions have been generally accepted in industry the user acquires an interest in seeing that duplicate machines remain available, and this may increase the difficulties of introducing some new standard when, in the process of development, the time arrives that the standard should be changed. In order to secure a favourable reception of BS 2083 it was necessary to give assurance of the continued availability of such machines covering a period of at least five years.

The initial standard was restricted to TEFC enclosure so as to concentrate attention on a type of motor that appeared to offer most scope for motor applications in the range of outputs considered. The details of the standardisation are familiar, but a few special features may be noted here.

It was considered by the manufacturers that use should be made of existing dimensional standardisation as far as possible. The American NEMA (National Electrical Manufacturers' Association) dimensions of MGI : 1949 represented the most complete dimensional standardisation available and it was therefore decided to utilise this series of frames. The NEMA steps in horse-power were also adopted, these corresponding to preferred horse-powers in the table in BS 2613, Clause 11, but each frame size was rated up a step—hence the expression 'NEMA plus one' used to describe BS 2083 horse-power assignments. This up-rating was essential, otherwise the new motors would have been physically larger than those in common use in British manufacture at the time. A new frame—B 183—had to be added at the bottom end of the range and the shaft dimensions of all sizes increased to correspond with the higher horse-power rating. These facts emphasise the important point that BS 2083 is primarily a British Standard.

At the same time, by de-rating and reducing shaft dimensions, it was possible to adapt the machines to NEMA MGI : 1945 requirements. In a revision of BS 2083 : 1956, flange mounting dimensions were added based on the NEMA 'D' flange but again with an extension to a smaller flange for the B 183 motor.

Ventilated Machines

Turning now to ventilated machines, a few firms produced a modified version of BS 2083 using ventilated motors with the standardised main dimensions, but such machines are not to be confused with the British Standard for ventilated machines that had already been foreshadowed.

While BS 2083 was still under consideration, the NEMA authorities were engaged upon a revision of the American Standards and ultimately established MGI : 1955. This revision, while retaining the familiar horse-power steps, introduced a complete change in dimensions in accordance with the most up-to-date technical developments in the USA. The NEMA 1949 standard was in inch units and followed a series of 'preferred numbers'; that is, certain dimensions of successive frame sizes increased in a geometrical progression. The new series—NEMA : 1955—retained these features but, by dropping some of the previous frames and introducing new sizes where necessary, a range was achieved having two lengths of frame for each step in diameter; an improvement on the previous series. Moreover the 60 c/s standard American frequency made possible the introduction of motors that were smaller in size than the 50 c/s motors to BS 2083. It was evident that any British Standard for ventilated motors would have to take account of this new NEMA series of frames.

Class 'E' Insulation

American motors were on a CRPO basis, the overload being given as a 15 per cent service factor, whereas the intention of BS 2613 : 1955 was that, in due course, all British machines should adopt CMR. Morevoer, CMR was a generally accepted Continental basis of rating. It has already been noted that a change to CMR, while retaining Class 'A' insulation, would not by itself result in a worthwhile cost saving below about 50 hp. If, however, a change to CMR could be accompanied by the use of some new development whereby the electrical materials could be more heavily loaded, such as using an insulation with higher temperature limits than Class 'A', then the required increase in rating might possibly be achieved.

Investigation showed that a frame size could be saved by using the new Class 'E' insulation already accepted in many European countries and included for the first time in a British Standard in BS 2613 with a limiting temperature rise of 65 deg C CMR.

The proposed range of ventilated motors of 1 to 50 hp were based on Class 'E' insulation with CMR with 65 deg C temperature rise. Horse-power steps followed the preferred horse-power series of BS 2613 and dimensions corresponded to the new NEMA Standard MGI : 1955, but each frame size was again rated up one step in horse-power and the shaft dimensions adjusted accordingly.

In order to gain general acceptance of these proposals, users had to be satisfied that increased temperature working would prove acceptable in practice and that the inevitable reduction in electrical performances that must accompany the up-rating of frame sizes would be offset by the saving in cost.

As an interim measure a list of

Fig 7. Class 'A' insulated induction motor in range from 1 to 50 hp

Fig 8. Induction motor to BS 2960

50 deg C ratings was prepared that could be utilised in the few special cases where site conditions do not allow 65 deg C machines to be employed.

As a result, in January, 1958, BSI published BS 2960 : 1958, standardising these ventilated Class 'E' motors, and manufacturers proceeded to develop and market machines to this new standard. Experience has shown that these motors have gained full acceptance in industry, practically superseding previous Class 'A' motors of similar output; moreover, resort to reduced ratings and temperature rises has proved rare.

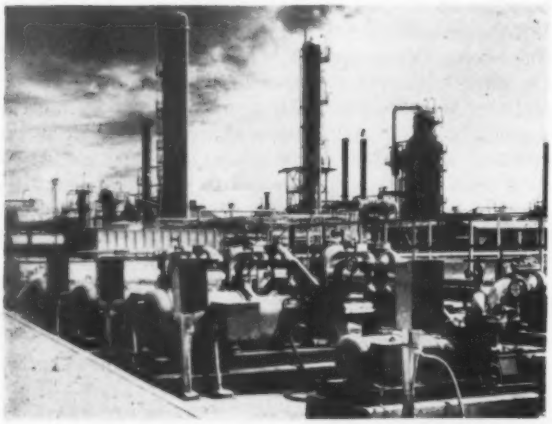
The up-rating of motors in this manner tends to establish a new relationship between the maximum torque performance and the full load torque of the continuous nameplate rating because the rating increases have been secured by higher thermal loading and not by any increase in magnetic flux levels. While the new motors give the 100 per cent momentary overload torque required by BS 2613, the margins in hand in excess of BS 2613 requirements are not so large as was often the case when Class 'A' machines of larger frame size were supplied. Where maximum torque performance is of prime importance, as for example in certain machine tool duties, some re-alignment of the motors with their respective duties has been found necessary.

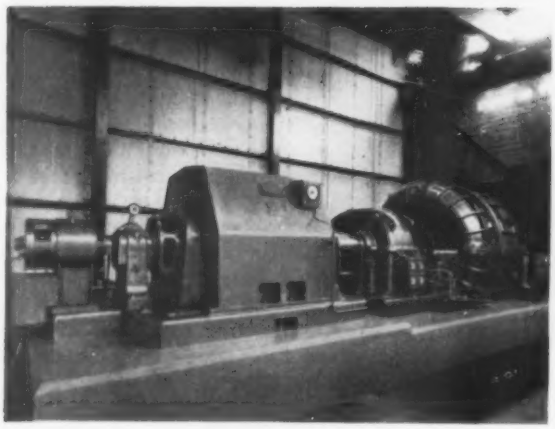
Class 'E' TEFC Motors

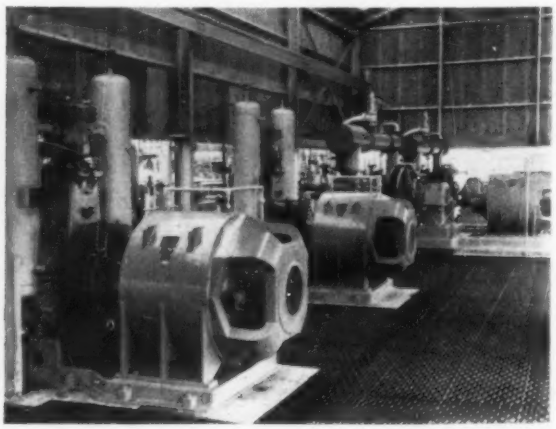
As might be expected, there have been repeated requests from users themselves for a revision of BS 2083 introducing Class 'E' insulation. Manufacturers have carried out the necessary investigations and have found that with the possible exception of one or two 3 000 rev/min machines at the top end of the range, it is possible to build TEFC motors to the same standard dimensions and with the same horse-power assignments as the ventilated motors of BS 2960. It is proposed that these machines should carry the prefix letter 'D' to distinguish them from the ventilated machines which have the letter 'C'. Fig 9 illustrates a type 'D' TEFC motor in this range. It must of course be pointed out that BS 2960 applies only to ventilated motors, and the TEFC machines can only be introduced as a counterpart having the same main dimensions and horse-power assignments as the ventilated motor built to the National Standard.

It would be unwise in such an article as this to predict either a period of stability or further changes, but the record of the past has been one of almost continuous development. Moreover, changes have proceeded in steps, retaining preferred horse-power assignments so that the necessary balance between cost and performance could be maintained.

Some Specialised Industrial Motor Applications







These three photographs show some interesting industrial motor installations carried out by Bruce Peebles & Co Ltd of Edinburgh. (Top left) *A range of outdoor flameproof squirrel-cage motors in service at the British Petroleum Company's Kwinana oil-refinery in Western Australia.* (Bottom left) *A 2 920 bhp (0·8 pf leading) 2 200 V 1 800 rev/min 3-phase 60 c/s synchronous motor driving a fan-blower unit at a Canadian nickel mine.* (Bottom right) *The interior of the hydrogen compressor house at the Kent Refinery of British Petroleum Co Ltd showing in the foreground two 50 bhp 440 V 368 rev/min, and in the background two 250 bhp 3 300 V 485 rev/min flameproof squirrel-cage motors (certified Group 2 gases) driving hydrogen compressors. The hydrogen hazard made it necessary for the motors and their terminal boxes to be pressurised with dry instrument air. Air-to-air cooling is employed. The air within each motor is circulated by fans on the ends of the rotor through the rotor core, through ducts in the stator core, over the end windings, to cooling tubes which almost fill the space between the stator core and frame*

Ward Leonard Planer Drives

J Shaw *

THE war years, and the prevailing conditions since the war, have demanded that all machine tools should be used to the limit of their capacity. Planers are no exception in this urge for greater productivity and it is not surprising that the drive of these reciprocating tools should have been the subject of much reconsideration in recent years.

Operating requirements of planer table drives consist mainly of the following:

Infinitely variable speed control
High table speed and cutting power
Speed stabilisation
Rapid, smooth, and accurate reversal
Rapid and frequent working cycles
Simple control and long life of drive.

Of the several methods available for driving these reciprocating tools, by far the most popular for its simplicity and proven trouble-free operation is the Ward Leonard Planer Drive. This drive has been progressively improved over the 50 years since its inception and many features have been added; the fundamentals of the drive have however remained the same and are briefly stated below.

Principles of Operation

The motor driving the table has its direction of rotation determined by the direction of the generator excitation, and its speed determined by the magnitude of the generator excitation and also its own field excitation. Switches operated by tappets moving with the planer table select, via contactors, the required magnitude and direction of the field excitations. Two or more speed regulators are generally provided, one regulator controlling the speed during the cutting stroke, and the other controlling the speed (usually greater) during the idle return stroke. A further regulator may be provided which regulates the speed during one or more portions of the cutting stroke, this device being useful for the following reasons:

(a) When planing surfaces with gaps between them, the gaps can be traversed at a higher speed than is used while the metal is being cut.
(b) The tool can be made to enter and leave the surface of the metal at a reduced speed, thereby reducing shock at the tool and the job. Broken edges of planed surfaces are thus avoided and tool life is often increased.
(c) The speed can be reduced when planing a local hard area of metal.

The feature described above has come to be known as the 'accelerating' device. A 'retarder' device is sometimes adopted, particularly where the work involves planing up to a shoulder. In such cases it is important to ensure that the point of reversal is not altered when the speed during the main part of the stroke is altered by the operator. This device is arranged to drop the speed to a low value immediately before the reversing switch is engaged by its tappet.

In addition to the main drive on a planer, some means must be provided for actuating the feed. This is an intermittent motion, as opposed to the continuous feed motion of the lathe. The tool must be moved by an adjustable amount immediately prior to cutting metal on each working stroke. If a motor is used to drive the feed transmission, then the motor must be made to rotate by a definite number of revolutions and fractions of a revolution, including accelerating and stopping, just before the beginning of each cutting stroke. The number of revolutions and the amount of feed applied must be adjustable by the operator. Numerous ways, both electrical and mechanical, have been adopted in the past for providing the feed drive and it is essential that special consideration is always given to ensuring rapid and accurate application of the feed.

Methods of Applying Feed Drive

One of the earlier methods adopted by a British company which pioneered this type of drive was the use of a geared motor unit driving, via a variable throw connecting rod through a ratchet and pawl or clutch, the feed screw of the planer. Initiation of the feed was by means of an auxiliary contact on the cutting contactor on the control cubicle.

A spring-loaded 'Feed Knock-off' switch, mounted adjacent to the face of a disc fitted to the output shaft of the gear and actuated by means of a tappet fitted to the periphery of the disc, terminates the feed by applying

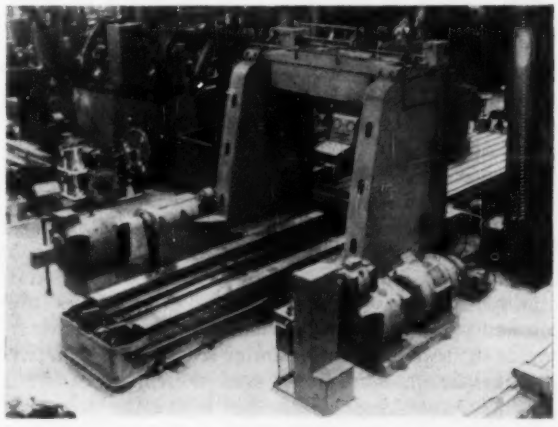


Fig 1. A typical Ward Leonard planer drive complete with planer in a motor manufacturer's works

* Lancashire Dynamo & Crypto Ltd

plug braking. The feed control automatically resets in readiness for the next reversal from the 'return' direction to the 'cut' direction.

A more recent development which has proved successful has been the use of a dekatron counter to control the number of revolutions of the feed motor. A switch situated on the control desk selects the number of revolutions required for the selected size of the feed, and an impulse unit fitted to the non-driving end of the ac feed motor supplies the reference for the count. After the motor has rotated for the required number of revolutions the control circuit is actuated, applying dc injection braking. Any overrun which takes place after injection braking has been applied is also counted by the dekatrons and taken into account for the next feed.

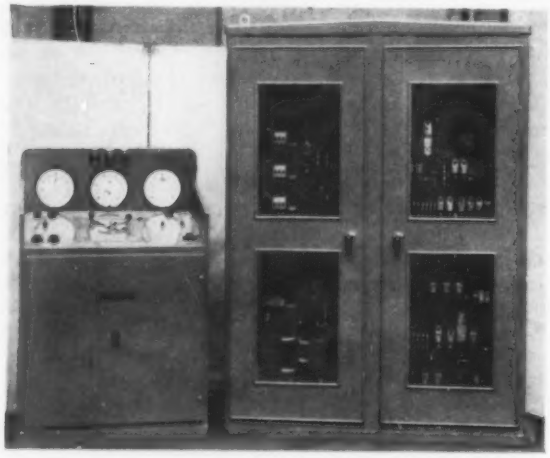


Fig 2. Control panel and contactor panel for a typical planer drive installation

Among other devices fitted on planers and acting in conjunction with the drive are tool lifting solenoids which, when energised on the idle return stroke, lift the tool tip clear of the work. Damage to the tool and work caused by the trailing of the tip on the work is thereby avoided. In addition to the above, various small motors are often incorporated for raising and lowering the cross slide, rapid traverse of the tool boxes (although these are frequently dealt with by the feed motor), the driving of oil pumps, cross slide rocking mechanisms and so on.

There are two ways of varying the speed of a dc motor —by weakening or strengthening its field, or by increasing or decreasing the armature voltage. Speed control by field variation is limited, whereas regulation of the armature voltage permits speed control from the maximum permissible speed practically down to zero.

The potential remaining across the unexcited generator does not however permit regulation down to zero revolutions because of the residual field of the generator; during stopping this residual field is sometimes suppressed by using the field winding of the generator by reversing its polarity and shunting it across the armature. In other cases a contactor is used to break the armature circuit. On braking, a resistance is shunted across the motor armature, thus bringing the motor rapidly to rest.

An inherent property of the Ward Leonard planer equipment which makes it eminently suitable for reversing drives is that the motor is reversed without any additional losses, while the kinetic energy stored up in the moving parts (less the relatively small friction and current losses) is released during the deceleration process. Electrical or mechanical reversing drives other than the Ward Leonard equipment do not exhibit this inherent advantage, which is particularly valuable when the reversals take place in rapid succession. Heavy work-pieces at high table speeds result in a large amount of kinetic energy becoming stored up in the parts in motion. Under such conditions even the rapid reversing drive may be very highly stressed, so one can imagine what happens to electrical and mechanical reversing drives which have no possibility of absorbing the kinetic energy, and in which any change in speed, even during the period of deceleration, will cause heavy additional losses in the form of heat. For example, slipping clutches and similar devices.

Defining the Optimum Conditions

The power of the planer motor is determined mainly by the specified maximum driving force on the table and the maximum table speed, even when maximum force has to be applied only at the lower table speeds. Moreover, since the motor will reverse more easily and quickly the slower it is rotating, a definite maximum motor speed must not be exceeded if optimum conditions are to be obtained.

The size of the variable voltage generator will depend on the electrical data of the planer motor it has to feed, and on whether armature voltage control or armature plus field control is adopted for varying the speed of the main driving motor.

The majority of planing machines cut in one direction only. In consequence the reciprocating motion of the table consists of alternate cutting (or work) and return (or idle) strokes. The speed of the return stroke should always be adjusted to the maximum value permitted by the length of the stroke and the work in question, so as to keep the idling time in the work cycle as short as possible.

During the return stroke the cutting force vanishes and the only force on the table is that required to over-

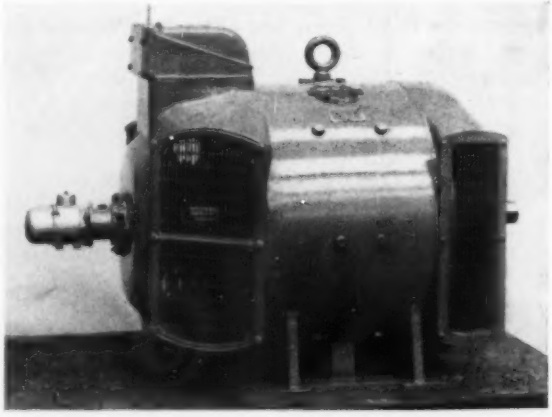


Fig 3. Main table drive motor showing tachometer on non-driving end

come friction; this force is a function of the combined weight of the table and work-piece and of the coefficient of friction. If however a relatively short stroke is employed, then nothing will be gained if the return speed is set at a maximum, because the accelerating time required to reach this maximum speed will exceed the time taken to complete the return stroke. The speed of the table will therefore never reach the maximum set by the regulator and overheating may be caused by the relatively high current required during the accelerating period, together with the current due to reversing.

The machines constituting the planer drive are always chosen and mutually adjusted in such a way that a single control impulse suffices to ensure that the required functions (*eg* change of table direction and speed deceleration and stopping the motor, and speed stabilisation during load fluctuations) are always carried out with the same accuracy and rapidity even after years of service. The machines are effectively protected against all overload. Even in the event of failure of the ac supply, the planer motor is instantly braked, since the fields of the dc machines are excited only as long as the motor-generator set runs and the generator absorbs the kinetic energy released during the deceleration process.

The design consideration of planer drives must be complex in order to ensure final simplicity. All apparatus and equipment which is not essential represents an unnecessary source of breakdown and must be dispensed with. Equipment subjected to the heaviest duty, such as reversing contactors and switches, has to be designed to withstand millions of operations over many years and a good deal of experience is required in this respect. Attention must also be paid to the correct design of operating controls, since the more convenient is the layout, the shorter are the setting-up times.

The illustrations accompanying this article show typical examples of various features of this type of drive as manufactured by a well-known British company.

A Computer Method of Determining the Variation of Induction Motor Magnetisation with Speed

B J Chalmers, B Sc *

Introduction

It is the purpose of this account to demonstrate, by means of an example, the manner in which digital computers may be used to perform calculations which would normally be far too lengthy and tedious for accurate manual solution. The organisation and arrangement of the particular calculation described is typical of the type of procedure often employed in digital computer programmes and illustrates the repetitive use of one set of programme instructions in an iterative calculation. This technique utilises fully the arithmetic and logical facilities of the computer and simultaneously achieves the maximum economy of storage space within the computer.

The problem considered is the reduction of the flux-density in a polyphase induction motor caused by the primary leakage, and the consequent variation with load of the flux-density and magnetising current. These effects are almost uniformly ignored in design calculations, though most designers of induction motors will quite readily agree that the flux-density at standstill (*ie* the starting condition) may be only one half of that at no-load or at full-load.

Theoretical Considerations

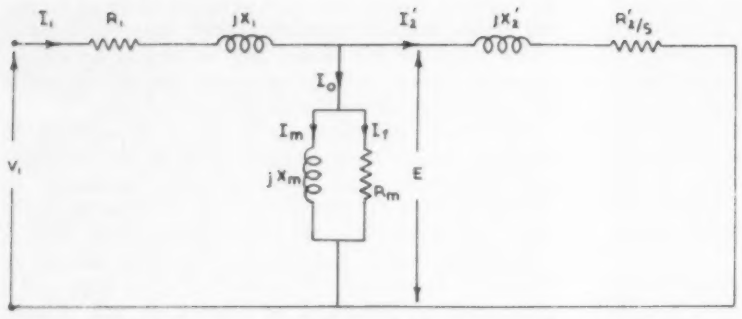
The theoretical basis of the problem is most easily approached by reference to the equivalent circuits which are commonly used to represent the polyphase induction motor.

* Department of Electrical Engineering, University of Bristol

The 'exact' form of the equivalent circuit of one phase of the motor, which may be derived by standard theoretical treatment, is shown in Fig 1. Performance figures over the speed range from zero to synchronous speed are obtained by solving the circuit for values of the fractional slip '*s*' from unity to zero. Fig 1 also includes a vector diagram illustrating, for one particular value of the slip, the vector relationship between the various phase quantities.

It is however far more common practice to determine induction motor performance by use of the approximate form of the equivalent circuit, or by use of the well-known circle diagram derived from this circuit, both of which are shown in Fig 2. Obviously, the main reason for preferring this approximate form is that the solution of this circuit is much less tedious than the repeated solution of the exact equivalent circuit, since the very simple circle diagram may be used.

The essential difference between the exact and the approximate representations of the induction motor is that the approximate form neglects the reduction of the main flux arising from the stator leakage impedance, so that the flux-density and magnetising current are assumed to be constant. The magnitude of this discrepancy will be demonstrated by the results of a particular set of calculations performed using a digital computer, these results being presented in the form of current vector loci which are typical of the loci obtained using the exact equivalent circuit.



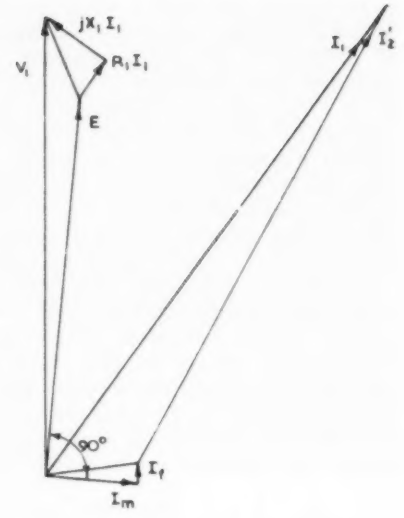


Fig 1. (Left) *The 'exact' equivalent circuit of one phase of an induction motor*

(Right) *Vector diagram illustrating the vector relationship between the various phase quantities for one particular value of slip*

To introduce these calculations, the following points are noted with reference to the exact circuit and its vector diagram given in Fig 1:

(1) The magnitude and phase of the induced emf (E) alter as the slip (s), and consequently the current (I_1), alter.
(2) The air-gap flux-density (B_g) is proportional to E.
(3) I_m is determined from the air-gap flux-density, and from the (non-linear) magnetisation curves of the iron magnetic circuit.
(4) I_m lags by 90° in phase behind E.

It is therefore evident that the magnetising current alters in both magnitude and phase as the stator current varies, due to both the variation of the flux-density and to the non-linearity of the magnetisation curves. The subsequent section of this paper describes the digital computer programme for the evaluation of these effects.

Arrangement of the Computer Programme

A block diagram illustrating the arrangement of the calculations for automatic computation is given in Fig 3, the procedure represented there being repeated for each value of the slip.

As indicated by the diagram, an iterative calculation method is used, in which an initial estimation or approximation is successively adjusted until the result converges to within a small tolerance of the correct solution.

A preliminary value of the magnetising reactance (X_m) of the equivalent circuit is obtained using the no-load value of the air-gap flux-density and the corresponding values of induced emf and magnetising current.

A first solution of the exact equivalent circuit then gives a new value of E, from which new values of B_g, I_m, and X_m are obtained. On each iteration, reference is made to the magnetisation curves of the iron magnetic circuit when calculating the magnetising current, so that the added refinement of taking into account the non-linearity of these curves is achieved.

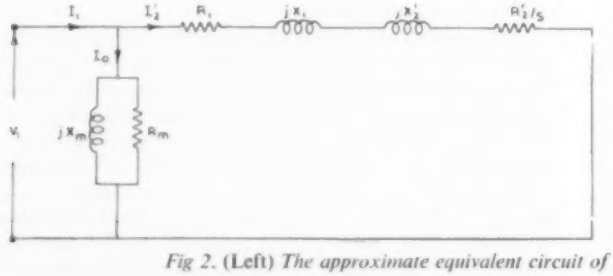
Assuming that the solution is obtained to a satisfactory degree of accuracy when successive values of the induced emf are within $\pm 0{\cdot}1$ per cent, it has been found that about three iterative loops are usually necessary to meet this requirement, the time taken being of the order of five seconds.

A Set of Typical Results

A set of typical results for a 3-phase, 50 c/s wound-rotor induction motor is presented in graphical form in Figs 4 and 5.

Fig 4 shows the variation in magnitude and phase of the magnetising current vector with respect to the applied voltage reference vector as the slip is varied through its range from unity to zero. It is observed from this diagram that the magnetising current vector follows, approximately, the arc of a circle. This result was first obtained theoretically by a geometrical proof published* in 1928.

* L H A Carr, 'The Circle Diagram of the Induction Motor', JIEE, **66** (1928), p 1174



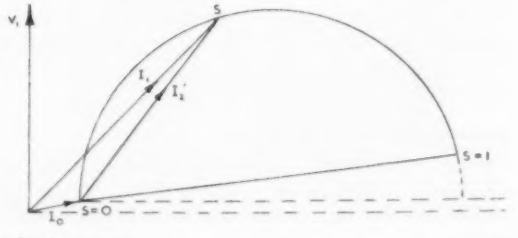


Fig 2. (Left) *The approximate equivalent circuit of the induction motor*

(Right) *The circle diagram derived from the approximate equivalent circuit*

The locus generally forms part of a circle whose diameter is of the same order as half the numerical value of the no-load magnetising current, since the stator and rotor leakage impedances are usually of similar magnitudes. This type of relationship has probably been long forgotten, because of lack of useful employment, until the recent developments in the application of digital computers to engineering design have provided as a by-product the opportunity for making accurate calculations.

The complete locus diagram of stator, rotor and magnetising currents is given in Fig 5, and this may be compared with the more common approximate form illustrated in Fig 2. Fig 5 also serves to illustrate that the variation of the magnetising current relative to the load current is usually so small that it has little effect on the overall performance of an induction motor. The iron loss due to the mutual flux is of course also decreased as the speed is decreased, but the rotor iron loss, and the iron loss due to leakage-flux, are increased at the same time.

It should be added that the power component of the magnetising current, representing the power loss in the magnetic circuit, was too small in this example to warrant its inclusion in the diagrams.

Conclusion

The calculations performed using the method described in this account have been shown to yield results which are in agreement with one of the classical theories of the polyphase induction motor. While these results are mainly of theoretical interest only, the method adopted for their determination serves to demonstrate the power of the digital computer as an aid in complex calculations, and to demonstrate the iterative techniques so often employed with computers.

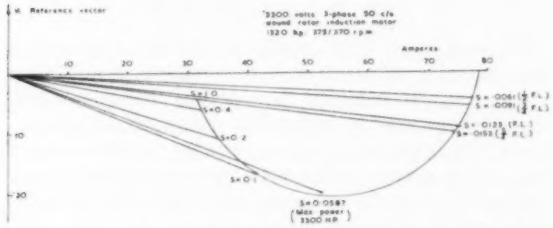


Fig 4. Locus of magnetising current vector as the slip varies from unity to zero

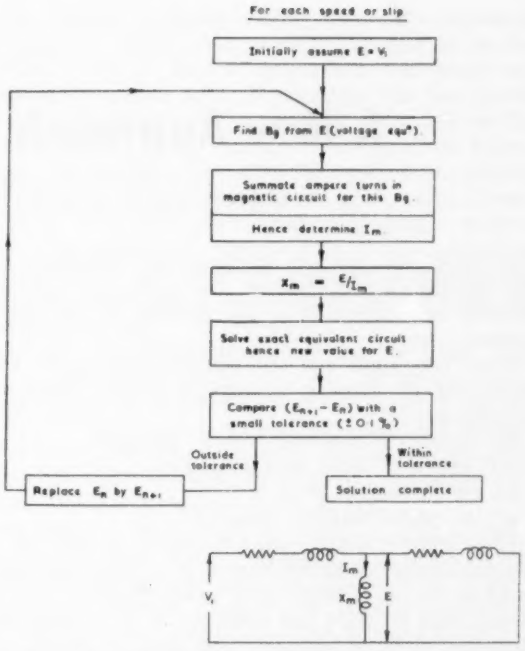

For each speed or slip
Initially assume E = V1
Find Bg from E (voltage equ^n)
Summate ampere turns in magnetic circuit for this Bg
Hence determine Im
Xm = E/Im
Solve exact equivalent circuit hence new value for E
Compare (En+1 − En) with a small tolerance (± 0·1 %)
Outside tolerance
Within tolerance
Replace En by En+1
Solution complete
Im
V1
Xm
E

Fig 3. Block diagram showing arrangement of the calculation for automatic computation

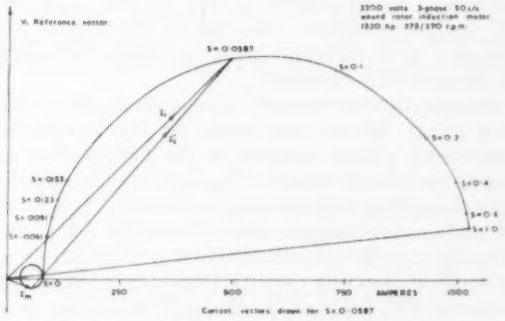


Fig 5. Complete locus diagram of stator, rotor and magnetising currents as the slip varies from unity to zero

List of Principal Symbols

V = Applied voltage per phase
I = Phase current
R = Resistance per phase
X = Reactance per phase
E = Induced emf per phase
B_g = Mean air-gap flux density
s = Fractional slip
Suffix *1* refers to stator quantities
Suffix *2* refers to rotor quantities
Suffix *m* refers to magnetisation circuit.

A New Approach to AC Motor Control

A VERSATILE INDUCTION COUPLING UNIT

THE TASC unit, recently developed and introduced by Pye Electric Ltd (Lowestoft Division), represents a radically new approach to the problem of ac motor control.

Some two years ago the company was given the assignment of devising a coupling to the following requirements:

(a) accuracy of control to within 3 per cent
(b) capable of cheap mass production
(c) no slip-rings or brushes
(d) no special machine tolerances.

These considerations—and particularly the last one—dictated a complete reconsideration of existing techniques based on the use of large out-of-balance magnetic forces across small air gaps and resulting in heavy machines supported on large bearings. After some six months of intensive development work the basic theory of the new device was produced.

The TASC (Torque And Speed Control) unit is an inherently constant torque device. Its construction is shown in Fig 1, from which it will be seen that the induction coupling consists of two members (the input and output members) rotating independently and supported by a stationary fixed structure. A small air gap separates the members.

The input member consists of an input shaft carrying a poled rotor; this is surrounded by the torque tube mounted on a boss attached to the output shaft and forming the output member. The fixed structure consists of the casing ring which surrounds the torque tube at one end, and at the other end carries the exciter coil with its turns concentric to the axis of the rotor. Since the exciter coil is fixed, the need for slip rings is eliminated. This arrangement is reversed in the larger machines in the range, so that the input member carries the torque tube and the rotor forms the output member.

In operation, the input member is driven at a constant speed from a rotary source of power. When the exciter coil is energised from a dc supply a steady magnetic field

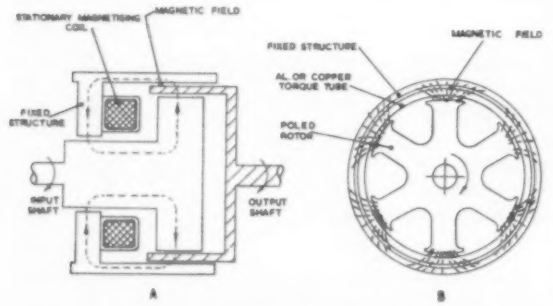


Fig 1. The basic construction of the coupling unit

which rotates with the poles of the rotor is set up (Fig 1b). This induces currents and therefore a magnetic field in the torque tube, and the two fields interact to produce a torque in the torque tube which tends to drive it in the same direction as the rotor. The energy is transmitted by the magnetic field, and there is no mechanical coupling between the rotor and the torque tube.

The magnitude of the induced torque is directly proportional to the value of the exciter coil current and almost independent of speed, so that the coupling is an inherently variable torque device and can be used to give either controlled torque or controlled speed.

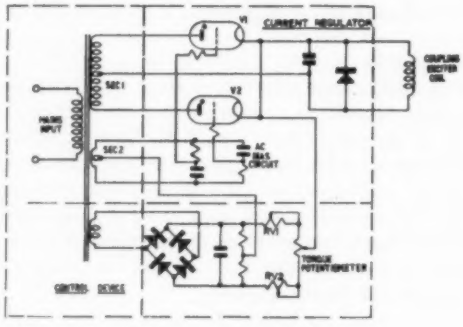


Fig 2. The basic torque control circuit

The unit lends itself readily to various applications and control systems. It will be apparent that torque control can be provided by varying the exciter coil current from the dc source by means of a rheostat. Another method is to use a variable transformer fed from an ac power source with the transformer output rectified to feed the coupling coil. In both cases the device can be calibrated in torque units.

A controller with a more general application, and particularly for remote control by low power sensing devices, makes use of a thyratron current regulator which also allows the controlling actuator to be of a low-power type.

The basic torque control circuit is shown in Fig 2. V_1 and V_2 are xenon-filled grid-controlled rectifiers or thyratrons. Conduction occurs when the anodes are positive with respect to the cathodes if the grid potential is more positive than a critical value with respect to the cathode. Once conduction has been started the grid loses control and current flows as long as the anode is positive with respect to the cathode, the value of the current being limited only by the load impedance.

The two thyratrons form a full-wave rectifier, with their anodes connected in antiphase and the load return connected to the centre tap of the transformer. Control of the mean level of the pulsating dc applied to the exciter coil is obtained by controlling the grid voltage and

thus the point at which the thyratrons fire during the positive half-cycles of the applied ac voltage.

Two types of bias voltage are applied to the grids in series. The first is an ac bias voltage which lags by 90° on the anode voltage and which, if acting alone, would cause conduction over approximately half of the anode voltage cycle. Its function is to ensure that the point at which firing occurs is clearly defined by the total of all the bias potentials.

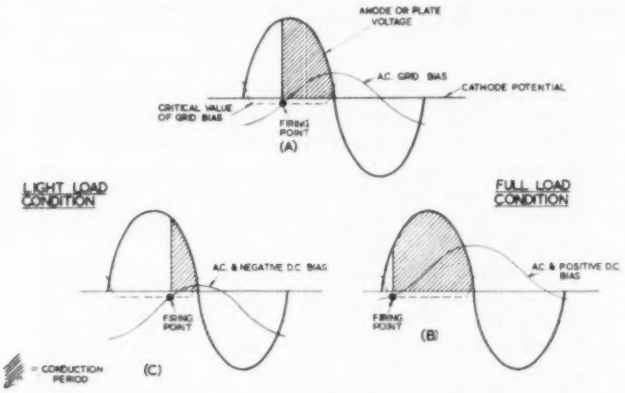


Fig 3. Thyratron wave forms produced by different bias voltages

The second is a dc bias which acts on both grid circuits to raise or lower the ac bias voltage wave relative to cathode potential. The two states are shown in Fig 3, where (b) is the result of a positive value of dc bias which causes conduction to occur over the whole positive cycle of anode voltage to give maximum output current from the regulator, and (c) is the result of a negative value of dc bias which causes conduction to occur over a small part of the positive anode voltage cycle to give a near minimum value of output current from the regulator.

The dc bias is derived from the torque potentiometer and is varied from the positive and negative limits to give a full range of control. The variable resistors RV1 and RV2 vary the maximum and minimum values of current respectively. If required, the torque potentiometer may be replaced by a remote sensing device or potentiometer.

For speed control applications a closed loop system is used to control the exciter current, as shown in Fig 4.

The exciter coil is fed by a current regulator, the output of which is controlled by a dc bias obtained from a difference unit. Two voltages are injected into the difference unit: a voltage proportional to the required speed set on the dial by the machine operator, and a voltage proportional to the speed at which the output shaft of the TASC unit is actually turning, obtained from a tachogenerator. The difference voltage derived from these two voltages acts upon the current regulator and adjusts the exciter coil current to correct for the speed difference by adjusting the torque available on the output shaft.

Since the voltages are of opposite polarity, the resultant dc bias determines the total bias level operative on the thyratron grids at any instant. The final bias level determines the point at which conduction of the thyratrons is initiated and thus the mean level of the direct current to the exciter coil.

The machine excitation is either increased or decreased to adjust the output shaft speed to the value set by the operator, and as this is approached, the speed and feedback potentials approach equality. The final stable state is such that the exciter current is determined by the torque required by the load at the set speed. At higher speeds the feedback bias will reduce the exciter current by negatively biasing the thyratron grids, and at lower speeds it will increase the current by applying a positive bias. The amount of effective bias at any instant is determined by the load torque, and the difference error required to result in the torque generation represents the speed differential.

Among the advantages claimed for the TASC unit are its continuous rating, with the full torque value variable over the whole of the speed range; it can be controlled right down to stalling indefinitely and without overheating; the control system is simple and regulation is fast and highly accurate; its construction is robust and no maintenance is required during its life.

Its potential applications are almost as wide as those of electric motors, and it is expected to be in use in the near future on such equipment as machine tools, cranes, winches, coil winding machines and laundry machinery, and later in such applications as fans, printing machines, feeders, mixers, and welding machines.

Initially the unit is being produced in $\frac{1}{4}$ and $\frac{1}{2}$ hp ratings, and larger models of 1 and 10 hp ratings are now being finalised. As the design of the machine lends itself readily to large batch production, it can be marketed at an attractive price.

The TASC unit is an entirely British invention and development, and designed to make an important contribution in the modern field of control requirements.

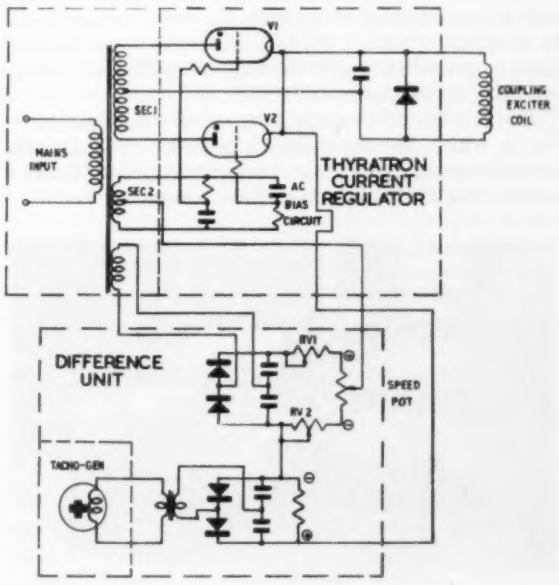


Fig 4. Circuit diagram of the closed loop system used for speed control applications

Test Plant for Large High-Speed Motors

A NEW APPLICATION OF THE BACK-TO-BACK SYSTEM

THE present-day trend in power station practice towards ever larger generating units has brought about a demand for larger boiler auxiliaries, including boiler feed pumps up to 10 000 hp. This has resulted in the design and construction of 2-pole and 4-pole induction motors which are considerably larger than any previous types, leading in turn to a demand for test equipment capable of giving these motors stringent full-power tests in the manufacturers' works.

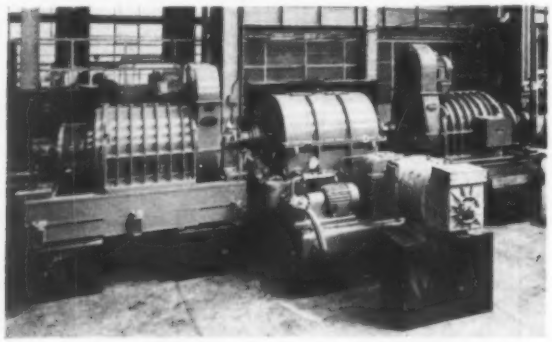
The General Electric Co Ltd has accordingly developed and installed test plant for large high-speed induction motors and synchronous machines up to 10 000 hp at 3 000 rev/min which is a variation of the back-to-back system in which the only power required from the supply is that needed to meet the mechanical and electrical losses.

Eliminating Power Dissipation Problems

Full load tests of very large induction motors create considerable problems. For example, to load a 10 000 hp machine fully requires a power supply of 9 000 kVA, and it would be both difficult and costly to dissipate this amount of power. The use of the differential gear box completely eliminates this problem.

The test equipment developed by the GEC makes full use of the fact that an induction generator delivers power only when it is being driven above its synchronous speed. In order to operate a back-to-back test, some method must be provided to give the required differences in the speeds of the machines under test.

This is achieved by using an epicyclic differential gearbox in which the slip energy is provided by a variable speed dc motor feeding into the planetary gear of the unit and varying the loading on the machines under test.



This shows the arrangement of the test equipment with two large 2-pole induction motors coupled to the differential gearbox for testing

The special gear unit, which was made by David Brown Industries Ltd, is continuously rated for 10 000 hp at 3 000 rev/min with a maximum shaft differential of 100 rev/min (*ie*, 3 050 and 2 950 rev/min). It is built as a self-contained unit with its own water-cooled lubricating system. The maximum rating for the slip energy motor is 200 hp at 1 500 rev/min.

Driving the differential shaft creates a speed differential between the motors by adding revolutions to one and subtracting them from the other. In effect, one motor is braked and develops a torque while the other motor is accelerated, absorbs the torque of the first motor and delivers power as an induction generator. The loading on the machines is directly proportional to the rotational speed of the differential shaft.

The differential shaft motor provides the slip energy or the rotor losses, and the only power taken from the supply is that required to cover the stator losses.

Any pair of similar induction motors can be tested provided their output is reasonably high compared with the gear losses, and it is estimated that motors as small as 300 hp at speeds up to 3 000 rev/min could be tested satisfactorily.

Testing Synchronous Machines

The equipment can also be used for testing synchronous machines by coupling a hand-operated gear unit to the differential gear train in place of the driving motor.

A synchronous motor coupled to one main shaft and running at synchronous speed would not necessarily be in phase with a similar machine coupled to the other end of the shaft and connected to the same supply, but they can be brought into synchronism by rotating the hand-operated gear unit.

When similar machines have been synchronised, their loading can be increased by rotating the hand gear unit, so causing their mechanical phase displacement to alter. One machine then becomes a synchronous motor and the other a synchronous generator which feeds power back to the supply. Each machine can be made to assume either function depending on the direction of rotation of the hand-operated gear unit, and the actual loading on each machine depends on the degree of mechanical displacement produced.

One important feature of this testing unit is that, if the electrical load should be suddenly removed, the mechanical displacement between each machine remains unchanged and the load can be re-applied without having to re-synchronise the machines. This is a particular advantage when synchronous machines controlled by automatic voltage regulators are being tested.

The Royal Institution and the Teaching of Science

Sir Lawrence Bragg, OBE, MC, DSc, FRS*

Editor's Note. *This account, by one of Britain's foremost scientists, of the unique organisation known as the British Institution has especial interest at a time when the training of scientists and engineers is becoming more and more important in every technically developed country.*

The Royal Institution is unique, both in the part it has played for nearly 200 years in Britain's outstanding contributions to the world's scientific knowledge, and in the peculiarly British manner of its foundation and progress to the international pre-eminence it enjoys today.

We believe this account will be of great interest to many of our readers in countries overseas.

IN order to follow the part which the Royal Institution has played in promoting science in Great Britain, one must know something about its start and its peculiar constitution. It was founded in 1799, at a time when general interest in natural philosophy was increasing, and 'Literary and Philosophical Societies' were being created at many centres in this country. Its founder was Count Rumford, a strange and romantic figure. He was an American, Benjamin Thompson, who had sided with this country in the War of Independence and escaped to England when Boston was evacuated in 1776. He entered the Civil Service and became an Under-Secretary in the Colonial Office. He had scientific interests and was elected a Fellow of the Royal Society in 1779. Subsequently he entered the services of the Elector of Bavaria, who created him a Count in recognition of his able administration. He was appointed Ambassador to England but to his mortification George III refused to recognise him in this capacity, as he was still a British subject. Being a very active man and finding himself with no occupation, he founded the Royal Institution.

Rumford's main interests were science and philanthropy and this explains the nature of the new body he created. He found a number of patrons to support the venture, and collected £30 000—a considerable sum in those days. A large house in Albemarle Street was purchased from the executors of a Mr Mellish, who had been shot through the head by a highwayman on Hounslow Heath. It was adapted to its new use with a lecture room built in its garden, library and reading rooms, workshops and stores.

The Beginning of Teaching

The new body immediately embarked on teaching as one of its main activities. Thomas Webster, its Clerk of Works, declared that it was Rumford's intention 'to do everything in his power to establish a school for science under the auspices of the Institution and particularly calculated for working mechanics, a class of men whose deficiency in knowledge proves one of the greatest drawbacks to the progress of art'. At the same time professors were engaged so that the nobility and gentry might enjoy scientific discourses.

Rumford, who seems to have been an overbearing man who liked getting his own way in everything, quarrelled with the Managers and departed in dudgeon in 1801; finances became very straitened, and the newly launched venture nearly foundered.

It was saved by Humphry Davy, appointed by the Managers at Rumford's suggestion just before he left. He was given a room in the house, furnished with coals and candles, and appointed Assistant Lecturer in Chemistry, at a salary of one hundred guineas per annum. Davy proved to be a brilliant expositor, and he was at the height of his historic investigations into electro-chemistry. He started the scheme of membership, which put the finances straight. All London flocked to the Royal Institution to hear about science.

Research and the Royal Institution

Davy thus gave to the Royal Institution the character which it has had ever since. It is a private body, supported by its endowments, its members' subscriptions, and donations from private individuals and organisations interested in its work. Like other Societies, it has its lecture room, meeting rooms, and library. But—and here it is unique—it also has professors, a laboratory, and a residence in the building, like the Master's Lodge in a College, for a Director of the Laboratory who acts as host for the guests of the Institution. Its interests are the diffusion of scientific knowledge, in particular by popular exposition, and the prosecution of research.

The Royal Institution has played a great part in the promotion of science in this country. In the first place, the history of the research done here is really spectacular and the reason is not far to seek. From 1800 onwards it was practically the only institution in this country where research into the physical sciences could be carried out in a place avowedly devoted to that purpose. University scientists who were so peculiar as to wish to do original research were expected to carry it out with their own resources and in their own homes. The first University physical laboratories—the Clarendon at Oxford and the Cavendish at Cambridge—were not founded till 1870. So it is little wonder that Davy and then Faraday, the greatest chemist and physicist of their age, found a centre here for their work. Other professors have included Thomas Young, who founded the wave theory of light, Rayleigh, Tyndall, Dewar, and many others.

The influence on the diffusion of scientific knowledge has been exercised in a number of ways. A main one has been the Discourses, traditionally held on Friday

* Director of the Davy Faraday Research Laboratory of the Royal Institution

evenings during the season from October to June in the theatre of the Royal Institution. The Discourses are now held on Wednesday evenings in the summer term. A famous man is invited to give a popular account of his field of knowledge, to an audience composed of the members and friends whom they invite. No expert knowledge is expected from the listeners, they come from all walks of life, possessing only a common interest in the sciences and arts. These discourses are unrivalled as a means of getting a general view of what is going on in the scientific world.

The Christmas Lectures

Then there are the equally famous Christmas Lectures, 'adapted to a juvenile auditory'. They started with a course on astronomy by J Wallis in 1826 and Faraday gave the second series on chemistry. They have been held every year since then, except for a break in the war years 1939-43. Six talks to young people are given in the fortnight after Christmas and it is a tradition to do experiments on the grand scale. It is surprising to find how many people in all walks of life say that their interest in science was first aroused by attending these lectures when they were young. Their influence throughout the years must have been very great. Further, these lectures have been the incentive for a large proportion of the best popular books on science which this country has produced. Some thirty-four books based on the Christmas Lectures have been published from 1860 onwards.

Finally, there have been lectures on special subjects for the senior student, as a form of direct and continuous teaching. Davy and Faraday gave very popular courses, and were given permission by the Managers to take private pupils in the laboratory. Brande succeeded Davy as Professor of Chemistry and was very active in having private classes, and in 1826 the Managers set up a committee to enquire into lectures at the Royal Institution and warmly supported these classes. The lectures were given at 8 o'clock in the morning!

But our great teacher was Tyndall, who passionately devoted himself to the cause of more science in schools and Universities. Tyndall and Faraday played a large part in starting the venture which grew into the Royal School of Mines and eventually into Imperial College. Above all Tyndall insisted on the value of experiments and demonstrations as contrasted with mere book-work, in full accord with the Institution's long tradition.

What of the Royal Institution at the present time? This grand old body has always lived dangerously. It has passed through a series of crises in its career, sometimes clashes of opinion about its management and function, sometimes grave financial straits. Indeed, function and finance have generally both been involved, because it has always depended upon the support of its members and friends, and this support can only be expected in return for the services to the community which it renders. It is perhaps all to the good that it has been necessary from time to time to review its position and reorient some of its activities.

Whereas throughout most of the nineteenth century there was little science teaching in Universities and almost none at schools, now every University has its laboratories and library; science is generously supported by the State, and students have a wealth of opportunities to hear about the latest discoveries at their colloquia and the numerous scientific conferences. Again, there have been great social changes. A body such as the Royal Institution can no longer be financed by its members' subscriptions and by wealthy benefactors, as it was in the past. The redistribution of wealth has made this impossible. The members are now contributing only a fraction of the running costs and the private benefactors have been replaced by the great industrial bodies. Before the war the Royal Institution was carrying on in much the same way as it had for a hundred years, but it was even then becoming clear that some reorientation was desirable, and changes due to the war made them urgently necessary.

The Royal Institution has two great assets. In the first place there are its traditions and its long experience in the art of scientific exposition. In the second place there is its 'House', with its magnificent lecture theatre, library, store rooms, and residence, situated so conveniently right in the centre of London. One has only to think of what a venture it would be nowadays to build such a centre within five minutes of Piccadilly Circus to realise what a heritage has been handed down to us from the past.

Cooperation with Schools

The guiding principle in planning is to ensure that its resources are used to the full for activities which the Institution is uniquely able to perform in modern times—the same principle that guided our predecessors in the last century. Twice a week during the school year the lecture theatre is filled with boys and girls, mostly from the Science Sixth Forms but on some occasions from lower forms, who come to see experimental demonstrations which illustrate their courses at school. The resources of the Institution can be used to stage these demonstrations, and industrial firms and other organisations have always given their help without stint. Some 20 000 free tickets are issued each year and it is hoped to increase the number considerably. The venture is financed by industry and various organisations. Occasions are arranged when parties of teachers can meet the leaders of research in this country and their teams and hear of the latest discoveries. A 'Library Subscribership' is open to teachers who can then use the Library and consult the staff about demonstrations. A very considerable measure of success has attended these new ventures. The Discourses and Christmas Lectures continue in the traditional way, and there is a flourishing research school in the fields of X-ray analysis and metal physics.

I end by quoting from a discourse delivered by Faraday exactly a hundred years ago. He was talking about the full recognition of science as a branch of education:

'It teaches us to be *neglectful* of nothing; not to despise the small beginnings, for they precede of necessity all great things in the knowledge of science, either pure or applied. It teaches a continual comparison of the *small and great*, and that under differences almost approaching the infinite: for the small as often contains the great in principle as the great does the small; and thus the mind becomes comprehensive. It teaches to deduce principles carefully, to hold them firmly, or to suspend the judgment: to discover and obey *law*, and by it to be bold in applying to the greatest what we know of the smallest. It teaches us first by tutors and books to learn that which is already known to others, and then by the light and methods which belong to science to learn for ourselves and for others; so making a fruitful return to man in the future for that which we have obtained from men of the past.'

New equipment and processes

New Range of TEFC Industrial Motors

Three of Britain's leading electric motor manufacturers: *Associated Electrical Industries Ltd (Motor and Control Gear Division)*, *Crompton Parkinson Ltd* and *English Electric Co Ltd* have lately announced a new range of totally enclosed fan-cooled (TEFC) ac motors.

Using Class E insulation, the new motors will develop up to twice the power of previous standard totally-enclosed machines of equivalent frame sizes, and rating for rating, will be smaller, lighter and cheaper than existing motors using Class A insulation.

Class E insulation permits a maximum temperature rise of 65 deg C above 40 deg C, instead of the permitted rise of only 55 deg C with Class A insulation. Electrically, the new motors conform to BS 2613 : 1957, and dimensionally to a new British Draft Specification, while their fixing dimensions are the same as ventilated motors to BS 2960 : 1958. They are thus interchangeable with ventilated motors of equal rating. An important point is that they can also be supplied with fixing dimensions to NEMA specification and can therefore be made interchangeable with American motors of the same power. The fixing dimensions are moreover in accordance with the latest recommendations of the IEC.

The standard motor is suitable for the majority of normal applications, but by varying the rotor design, different starting characteristics can be produced to suit special requirements.

The range immediately available covers motors from 1 to 7·5 hp; an extended range from 10 to 40 hp will be available in the early Spring of this year.

Increased Range of Brake Motors

Additions to the range of electric motors incorporating a disc type electromagnetic brake as an integral design feature are announced by *Newman Industries Ltd*, who recently introduced the first complete range of British motors with this feature. The range now extends from fractional to 40 hp.

The brakes are suitable for building into any of Newmans fhp and industrial 3-phase motors (drip-proof or totally enclosed) up to 40 hp, but are not suitable for single-phase operation. A torque range from 3 to 120 lb/ft (4·46 to 178 kg/m) will eventually be covered.

For motors up to 3 hp the brakes have sufficient torque to deal with almost all applications, but for larger machines alternative brakes are available for each size of motor: one for normal duty with a retarding torque equal to or slightly greater than the motor full-load torque, and the other with a retarding torque of not less than 1½ times the motor full-load torque and intended for overhauling loads such as hoists, lifts and similar duties.

The new brake motor is standard in every respect apart from the special non-drive bracket on which the brake is mounted and the extension of the shaft to carry the brake disc hub. With totally-enclosed fan-cooled motors the brake is mounted between the fan and the motor; though protected by the cover, it is not totally enclosed.

In addition to normal horizontal mounting, the motors may be mounted with the shaft vertically up or down if required.

The brake is of the 'fail to safety' type (*ie* energised 'off') and operates from a 3-phase supply, with provision for manual release when it is de-energised. As the total movement of the braking mechanism is only of the order of ·02 in (0·508 mm) the brake is very rapid in operation.

Miniature Fluorescent Lighting Fitting

Victor Products (Wallsend) Ltd have recently announced a new miniature fluorescent lighting fitting with many novel features. The light output using two 12 inch (305 mm) 8 W tubular fluorescent lamps is 640 lumens for the first 5 000 hours of lamp life. The total load of the complete unit is 26 W.

The fitting is designed to comply with BS 2467 : 1954 which covers minimum safety requirements for lighting fittings for use with hot cathode tubular fluorescent lamps. Shrouded lampholders are incorporated to accommodate American, European or British standards of tube diameter.

The fitting, which is available as a complete unit, includes two warm white lamps, glow starter switch and power factor correction capacitors, and is therefore ready for immediate use. For security purposes a key is required to open and close the fitting; these keys must be ordered separately.

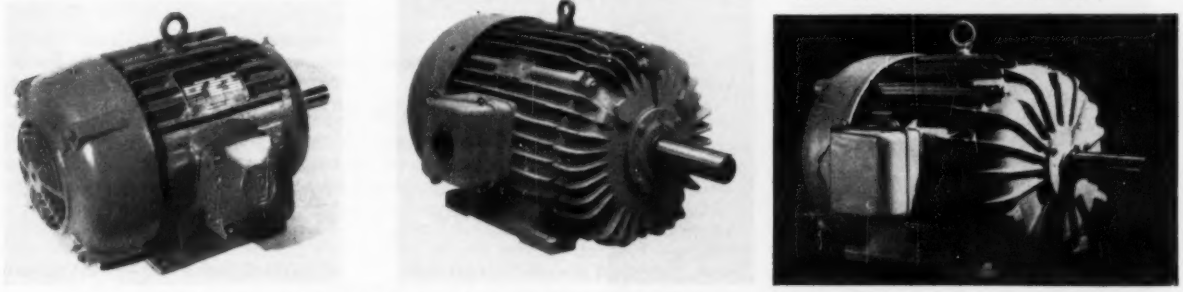
The Victor miniature fluorescent lighting fitting. The body is an aluminium alloy casting and the hinged cover is Perspex opal

Portable Contamination Monitor

A new compact transistor-operated monitor offering unique facilities for detecting radioactivity has been produced by *EMI Electronics Ltd*. It makes use of the EMI dual-phosphor technique and can be used for monitoring radioactive contamination on benches, clothing and similar objects.

The dual phosphor technique enables both alpha and beta contamination to be monitored simultaneously, and separate distinctive tones are provided for each radiation. The instrument is claimed to provide high accuracy over a temperature range of 0 to 45 deg C, and by means of a single switch it is possible to monitor the sum of alpha and beta contamination or either type separately, with the information displayed on a meter covering 0 to 5 000 counts a second. For monitoring very low alpha activities an electro-mechanical register is included to give a more accurate display at rates below about 6 a second.

The overall dimensions of the unit are 11½ by 8 by 8½ inches (292 by 203 by 216 mm); its weight is approximately 11 lb (5 kg) and power consumption 0·75 W. The all-transistor circuits enable it to operate for long periods from a battery supply.



Three typical examples from the new range of TEFC motors with Class E insulation described above. On the left is a 7·5 hp 'D' type motor by English Electric; next is one of the AEI type KN-D series, and on the right is a Crompton Parkinson Series 5 motor.

The New Electrolux Suction Cleaner

The well-known Electrolux suction cleaner made by *Electrolux Ltd*, 153-5 Regent Street, London W1, appears this year in a new version known as Model 65, for which the makers claim that it will do all the everyday household cleaning with only two tools.

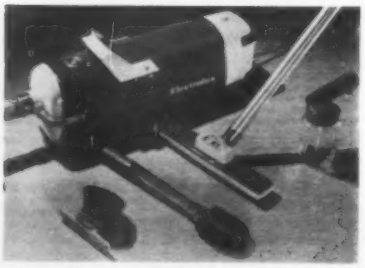
The new model retains all the basic features of previous models, including: quick-running motor; throw-away paper bags for easy dust disposal; air purifying pad to filter the exhausted air; tapered hose with revolving snap action coupling. Detailed improvements in the new model include plastic (instead of cotton or jute) braiding on the hose, making it easily washable; new style of handle for easy carrying which also provides wind-round storage for the flex, a new design of end clips giving easy access to the dust bag, and a telescopic extension tube which replaces the two tubes previously used.

The major features are in the two main cleaning tools. One is a combined carpet nozzle and floor brush, either of which is brought into action by a light pressure of the toe. Lifting the nozzle from the floor allows it to swing over on to its back, which has a special pair of brushes to pick up threads, fluff and animal hairs.

The other principal tool is a combined dusting brush and small nozzle for upholstery, curtains, clothes and so on.

There are two other accessories to cater for the less frequent household tasks: a crevice nozzle with an ingenious brush attachment with suction on both sides, enabling it to clean easily between the tubes of radiators or the slats of venetian blinds, and the sprayer for paint, carpet shampoo, insecticides and the like.

The body of the cleaner is made of tinned sheet steel, with end pieces of tough moulded plastic material. The motor is rated at 450 W, with double insulation to BS 1645. Electrical connection is by 20 ft (6·1 m) of tough rubber sheathed 2-core flexible cord. Weight is 12¾ lb (5·8 kg) or 13¾ lb (6·2 kg) including the flexible cord.

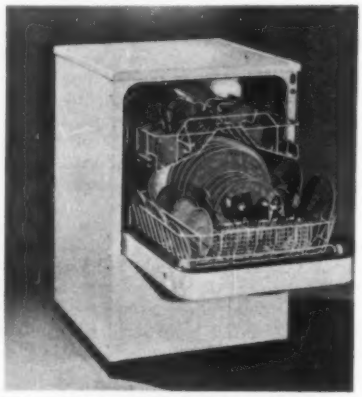


Electrolux Cleaner, Model 65, showing all four attachments

The 'Swanmaid' Dishwasher

Recently introduced by *Bulpitt & Sons Ltd*, St. George's Works, Icknield Street, Birmingham 18, the 'Swanmaid' is a fully automatic dishwasher designed for family and domestic use. It is made for front loading, which gives two advantages: the racks of crockery do not have to be lifted in and out of the machine, and the 'Swanmaid' can be teamed with other kitchen units to provide a continuous flat-top working surface.

Important features are that all washing and rinsing is done at a water temperature of 180 deg F (82 deg C), ensuring complete sterilisation of the contents and enabling them to dry off within the cabinet; the spray-jet arm is driven by water pressure only, so that the water is sprayed gradually at first and the articles are warmed up slowly before the full force of the swirling jets comes into operation; operation is entirely automatic, the machine starting as soon as the water temperature reaches 180 deg F (82 deg C), going through a timed cycle of one hot cleansing wash and two hot water rinses and then switching itself off.



The new 'Swanmaid' dishwasher with a typical load

Two filters—one coarse and one fine—continuously filter the recirculating washing water; as the waste outlet has no valve, food particles cannot be trapped in the seating to cause leaks or affect the water supply to the pump. Two safety features are incorporated: the door-button switch, which operates the machine, will not work if the door is not properly closed and latched, and if the door is unlatched or opened while washing, the machine will stop completely and will resume its normal cycle as soon as the door is closed again.

The machine is designed for ac supplies of 200/220 or 230/250 V. It incorporates a 3 kW water-heating element and a ¼ hp motor. The water consumption is 3 gallons (13·6 litres) per cycle. External dimensions are 23 in (58 cm) wide, 24½ in (61 cm) deep and 36 in (91 cm) high, and the finish is in ivory or white.

New Version of the Hoover Constellation Cleaner

Hoover Ltd have recently introduced a new model of their spherical Constellation suction cleaner and have at the same time announced a number of price reductions.

In the new Constellation, the suction inlet has been offset from the top centre towards the front, making possible a more convenient form of carrying handle and keeping the switch towards the operator.

A major improvement has been made to the cleaning tools by the introduction of a new design of carpet and floor nozzle. A low height all-plastic casing houses a full length polythene-backed brush which can be operated in a 'float' position for normal carpet sweeping or locked into a low position by foot control when cleaning hard surfaces. In this housing there is also a flexible plastic 'litter picker' with 'teeth' which disturb the litter and make it easy for the brushes and suction to deal with it.

There is a new plastic all-purpose nozzle incorporating a little picker, and a dusting brush and crevice tool are also supplied.

The exhaust air is deflected by baffles to give an air cushioning effect, so that the cleaner moves with only a gentle pull. A finger-tip operated suction regulator in the curved hose-end adjusts the suction to suit the various types of cleaning.

The double-stretch 'Hooverflex' hose is made of flexible plastic and reinforced with plastic-coated spring wire, and will stretch to twice its length—from 7 ft 3 in to 14 ft (2·2 to 4·3 m). There are also two aluminium alloy extension tubes.

A large volume 'Disposall' paper bag is fitted for easy and hygienic dust emptying. To allow for its fitting and removal and for maintenance, the cleaner is hinged in the middle and the joint sealed airtight by a flexible plastic gasket which also acts as a furniture guard.

The machine is doubly insulated and conforms to BS 1645 and other international specifications. It is fully suppressed against radio and television interference.

The motor is rated at 580 W, and the cleaner is very compact, being just over 12 inches (30 cm) high.

Sanding Attachment for Power Drills

A sanding and polishing attachment for use with portable electric drills and which incorporates a novel design feature has recently been introduced by *Stanley Works (GB Ltd)*, Sheffield, Yorkshire.

Known as the Stanley 'Swirlaway,' this attachment differs from the usual type in having a flexible ball joint incorporated between the drive spindle and the head. This permits the tool to be used at an angle to the work while keeping the sanding head itself flat on the work surface.

There is no tendency for the head to 'run away' or spin off the work and therefore no need to tilt the head to keep it under control. This eliminates the risk of edge marks or sand swirls on the finished work, and the makers claim that the 'Swirlaway' will give a smoother finish in less time than the conventional sanding disc with a rigid drive.

Another advantage claimed is that, because the whole surface of the disc is in contact with the work, there is 100 per cent distribution of the load, giving a longer life for the abrasive disc and a larger effective working surface, although the Stanley disc is 4 in (10 cm) in diameter as compared with the usual 5 in (13 cm) sanding disc. Furthermore, the flexible ball joint permits the use of a rubber-faced rigid metal disc instead of a flexible disc used with a rigid drive. Where the nature of the work demands, the 'Swirlaway' drive can be locked solid by a simple screwdriver adjustment.

It can be used with sanding discs of any grit and on a wide variety of materials.

A New Road Heating Installation

THE first major road heating installation in Great Britain has recently been commissioned on the Mound in Edinburgh.

The Mound is one of the principal thoroughfares in the Scottish capital; it is approximately one-third of a mile (530 m) long, and as it is built on a hill it has several acute bends and a substantial gradient throughout its length. It is thus a very serious hazard to traffic during severe winter weather.

When the Edinburgh Corporation decided to reconstruct the road, the City Engineer recommended that electrical road heating should be installed. The main requirements were (a) that it should prevent frost and snow lying on the road under normal winter conditions, but not necessarily be capable of dealing with abnormal conditions such as blizzards or drifting snow; (b) that a minimum of disturbance should be caused to the heating installation if the roadway had to be opened up for emergency repairs to the electricity, gas, water, telephone, and sewage services; (c) that the heating system should be installed with as little departure as possible from normal road laying or construction procedure, and (d) that the whole system should be fully automatic in operation, with an emergency cut-off to be operated by responsible city officials.

Total Loading of 896 kW

The design which was finally adopted called for a large number of relatively small heating panels approximately 16 ft (49 cm) square, each loaded to 4 kW and giving approximately 16·6 W of heating per square ft (929 cm^2) of road surface. The complete installation comprises 222 full panels and 4 half panels with a total loading of 896 kW and involving some 37 miles (60 km) of heating cables.

'Panelec' heating cables supplied by the 'Panelec' Heating Division of British Insulated Callender's Cables Ltd have been used exclusively, the total number amounting to 448. Each cable is rated at 2 kW and consists of a heating element of 12/·010 in (12/6·45 mm) 'Mancoloy' resistance wire, Terylene/glass roved, pvc insulated, and sheathed with high tensile heat-stabilised nylon. The cables were all fitted with factory-jointed cold tails of varying lengths according to the relative positions of the cables and supply points.

The 'Panelec' system was specified after sample cables had undergone the necessary field trials to establish loadings. The technique employed in laying the cables was to fix temporary spacing jigs to hold the cables in position while the infil of 0·5 in (12·7 mm) sand asphalt was laid and compacted with a light roller. The infil was taken as close to the spacing jigs as was conveniently possible to enable the anchoring jigs to be removed, so that the cables were free to move with any creepage that might occur either with the infil or with the wearing carpet. The latter was applied by a laying machine weighing some 14 tons, and finally 0·75 in (19 mm) of whinstone aggregate was rolled into the carpet by a 10-ton roller.

For the power supply, the South of Scotland Electricity Board built and equipped a special sub-station in the neighbouring Princes Street Gardens. This is supplied at 6·6 kV. The main equipment consists of a 1 000 kVA 6,600/415/240 V 3-phase 50 c/s transformer with a 1 600 A air circuit-breaker controlling the outgoing side of the transformer to a suitable lv board containing the ct metering.

From this board the supply is taken to three 400 A 3-phase 50 c/s contactors through suitable triple pole and central isolators. These contactors are sequence operated at 2-second intervals, thus minimising the load on the Board's system. The contactors feed the three sections of the installation through 48 watertight pavement distribution boxes, where the cable 'cold tails' are connected to suitable fuses. The contactors were supplied by E N Bray Ltd.

Obtaining Detailed Statistical Data

The whole installation is completely automatic in operation and is controlled by the prevailing weather conditions through moisture detectors, frost penetration indicators and temperature sensing units in the roadway, and similar units working in conjunction with air thermostats and snow detectors on a special control plinth which also contains an emergency cut-off unit.

In addition to the control equipment installed for the automatic operation of the heating installation, the Electrical Research Association in conjunction with the Road Research Laboratory have instrumented the roadway in order to obtain statistical data on the behaviour of the installation in all weather conditions.

The project was designed by the City Engineer of Edinburgh, Mr W P Haldane, MBE, B SC, MICE, MIMechE, MTPI, in collaboration with the South of Scotland Electricity Board.

Showing the method of positioning the heating cable before the sand asphalt carpet was applied

Electronic Telephone Exchanges

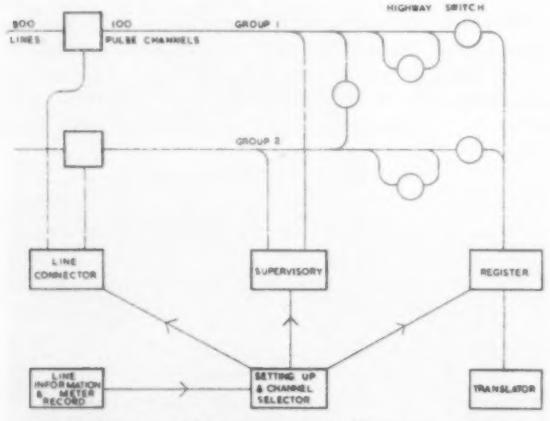
AN experimental electronic telephone exchange which is now undergoing exhaustive tests at the British Post Office Research Station in London is the first result of a unique example of co-operation between industry and a Government department.

It was realised some five years ago that a very big research and development programme would be required to find an effective answer within a reasonable time to the problems of applying electronic techniques to telephone switching. Therefore the five principal British manufacturers of telephone exchange switching systems and the British Post Office decided in 1956 to set up a Joint Electronic Research Committee. The Chairman is Sir Lionel H Harris, KBE, TD, Engineer-in-Chief of the Post Office, and the five manufacturers are:

Automatic Telephone & Electric Co Ltd
Ericsson Telephones Ltd
General Electric Co Ltd
Siemens Edison Swan Ltd
Standard Telephones & Cables Ltd

These six organisations represent a pool of their joint research and development resources, and they have undertaken long term studies to determine the best system to be employed and to obtain practical experience in designing and operating exchanges using electronic equipment.

Typical of some of the problems involved was that of contact resistance at terminals and connections. Because of the very low voltages used in the electronic circuitry, contact resistance had to be kept as low as possible, and lengthy investigations have therefore been undertaken into the contact resistances of different metals under widely varying operating conditions.



Block diagram of the experimental electronic exchange

The outstanding result of the co-operative effort is the new experimental exchange. Each member-organisation of the JERC has carried out a detailed study of a portion of the system, and the individual parts are now working together in the new exchange.

The introduction of electronics to telephone exchange design is expected ultimately to reduce the initial cost, to produce smaller equipment which will need less building space, and to give greater reliability because of the virtual absence of moving parts.

Operational Principles Described

Here is a brief description of the operational principles of the electronic exchange. In the conventional exchange, one subscriber is connected to another by metallic contacts on relays and selector mechanisms, so that, while callers are in conversation, there is a direct physical electrical path between them, and all the apparatus involved in that path within the telephone exchange is used exclusively by that one conversation as long as the call continues.

The development of electronic 'gate' circuits suggested the idea of using them instead of electromechanical switches, and experimental models of such systems have been demonstrated over the last ten years. However, it was not until experience in the computer field produced really fast-operating gate circuits that the possibility of substantial economies in telephone exchange operation could be realised.

By interlacing speech paths in time sequence, with the whole cycle being repeated fast enough to eliminate audible discontinuities, a large number of speech paths can share common apparatus. Selection of the required circuit for each different pair of callers engaged in a conversation is carried out by further gate circuits connected between the common multiples and the subscribers concerned. In addition, equipment is required to supervise the operation of the gate circuits; to register the wanted number of the subscriber who is being dialled; to translate the dialled number into signals to operate the appropriate gate circuits, and to record the cost of the call on a meter.

Time Division Multiplex Working

Basically, the new exchange employs the principle of time division multiplex and switched highways for the ultimate connection; each highway (or multiplex) can carry up to 100 simultaneous conversations and sufficient highways are provided to carry the traffic of the exchange. The exchange lines are arranged in groups, and each line in a group is connected by electronic gate circuits to a highway which is common to all the lines in that group. Other electronic gate circuits enable each highway to be connected to any other.

The number of subscribers in a group connected to a common highway is several times greater than the 100 simultaneous conversations which can be carried by the multiplex, and in a typical electronic exchange using this technique, up to 800 subscribers could be connected in

one group, as not all of them would be using their telephones at the same time.

The highways transmit speech and other signals to and from subscribers' lines in the form of amplitude-modulated pulses, each line using a pulse channel transmitting one of a series of interlaced cyclically recurring pulse trains with a repetition frequency in the case of the experimental exchange of 10 kc/s. Lines are connected to channels by applying suitably timed pulses to the gate circuits.

Magneto-strictive delay lines are used as temporary memories for storing the pulses which have been allocated to the subscribers' gates for connection to the multiplex, and for controlling the gates interconnecting the multiplexes. Magneto-strictive delay lines are also used as registers to receive information dialled by subscribers. They count and store the dialled pulses, obtain any translations which are necessary to route calls to other exchanges, and transmit digit pulses when outgoing routes are established. Delay lines also control the supervision of connections after they have been established. They connect dialling tones and ringing to the lines as necessary; detect answering and clearing, and arrange for the metering of completed calls.

A magnetic drum is used as a semi-permanent memory. This carries all the information relating to all subscribers' lines and junctions, and in this respect acts as the exchange 'library'. Another portion of the drum co-operates with the register equipment by providing the translation facilities mentioned earlier for routing the call to a local subscriber or to subscribers on other exchanges. Positions on the drum which are particular to each subscriber are used to record the accumulated total of calls to be charged to the subscriber, replacing the individual electro-mechanical registers provided for each subscriber in existing exchanges.

In the experimental model described here, functional divisions have been used as the basis of the co-operative development. Thus the multiplex and speech circuit equipments have been designed jointly by the Post Office and the General Electric Co Ltd; the supervisory equipment by Ericsson Telephones Ltd; the register equipment by Siemens Edison Swan Ltd; and the translation, metering, line information and other equipment jointly by Automatic Telephone and Electric Co Ltd and Standard Telephones and Cables Ltd.

When the tests of the experimental model have been completed, electronic equipment for about 1 000 lines will probably be installed within the subsequent two years for a public exchange in North London, and similar divisions of responsibility and manufacture will be adopted.

British Automatic Greenhouse at the Ghent 'Floralia'

IN response to requests from the organisers and from many visitors from other countries who saw this outstanding exhibit at Paris in April last year, the British automatic greenhouse will be shown at the Floralies Internationales—the famous international flower show—to be held in Ghent from 23rd April to 2nd May 1960.

The automatic greenhouse is a scientific exhibit consisting of the most modern type of aluminium greenhouse equipped with a large number of electrical devices designed to provide entirely automatically the perfect plant environment—a field of activity in which British electrical manufacturers have established a decisive lead.

At the Floralies Internationales de Paris last year, the automatic greenhouse formed one of the British exhibits and was awarded Second Prize in the Scientific section. In addition, 23 of the individual pieces of equipment in the exhibit also won awards, including a number of gold medals.

The exhibit at Ghent will be sponsored by the British Committee for Overseas Flower Shows with the cooperation of the BEAMA, and most of the electrical equipment will be supplied by BEAMA member-firms. The automatic greenhouse was conceived and planned by Mr A W Gray, of the Agricultural Advisory Section of the Electricity Council.

The objective is to provide, under fully automatic control, three separate climates and two seasons in one house. This is achieved by means of thermostatically-controlled air warming, bench and soil warming, and automatic ventilation in the main house, which is run as a moderate temperature house. The enclosed propagating case, which is equipped with separate space heating and bench warming, provides a separate and higher temperature climate.

The growing cabinet underneath the enclosed bench is also fitted with a separate heating installation and automatic ventilation to give yet a third temperature range. In addition, artificial lighting is installed which can be varied in intensity, colour, and day length. Thus in the growing cabinet it is possible to simulate automatically at any time of the year the temperature, light intensity, and duration of daylight appropriate to any season.

Of the three frames, the first provides a hot bed for raising early salad crops, etc, and is equipped with low-voltage soil warming. The second is a propagating frame and has thermostatically-controlled space heating and bed warming, and the third is for hardening off plants, with frost protection provided by a thermostatically-controlled mains voltage warming cable.

The principal suppliers of electrical equipment include: AEI Lamp and Lighting Co Ltd (8 ft (2·4 m) 200 W fluorescent lamps and daylight intensity controlled relay); British Insulated Callenders' Cables Ltd (pcp cables); E K Cole Ltd (thermotubes in 12 to 13 ft (3·7 to 4·0 m) lengths); J A Crabtree Ltd (distribution board, earth leakage and overload breaker, 12-way neon indicator panel); General Electric Co Ltd (conduit boxes and fittings); W T Henley's Telegraph Works Co Ltd (flexible pcp cables); Process Control Gear Ltd (rod-type thermostats); Sangamo Weston Ltd (time switches); Simplex Dairy Equipment Ltd (GEC) (soil warming cables).

Book Reviews

Dynamical Analogies. (2nd Edition). *By H F Olsen.* $9\frac{1}{4} \times 6\frac{1}{4}$ *in* (235 × 159 *mm*). *Pp xi* + 278. *Illustrated. Index.* (*London: Van Nostrand.*) Price 51s net.

The first edition of Dr Olsen's book, already well known to mechanical and acoustical engineers, is based on the fact that particular mechanical or acoustical vibrating systems may frequently be converted into analogous electrical circuits whose behaviour is much better known. In spite of the obvious importance of the subject there does not seem to be another book covering the same ground, and the appearance of a second edition is welcome.

The opportunity has been taken to introduce analogies that have become more prominent recently. In particular, three additional chapters have been included covering magnetic analogies and the fields of noise, distortion, and feedback. The chapters on mobility analogy and applications have been enlarged, while the introduction and definitions have been revised in the light of the new material included in the book.

The amount of space devoted to some of the applications still leaves much to be desired, and there is often little or no derivation or explanation of a problem, giving the impression of a catalogue of analogies. It therefore seems a pity that an extensive list of references could not have been included at the end of the book, as this would have been a valuable aid to the reader who is faced with a problem not specifically dealt with in the text. Also, in view of modern methods for the solution of electric circuit problems in general, the mathematics might have been brought up to date with Laplace Transformation replacing the less popular and less elegant Heaviside Calculus.

Nevertheless, in spite of its drawbacks, this second edition should prove a useful addition to the bookshelf of those concerned with the study of mechanical or acoustical vibrating systems.

H GOLDENBERG

Impulse Voltage Testing. *By W G Hawley.* $8\frac{3}{4} \times 5\frac{1}{4}$ *in* (222 × 146 *mm*). *Pp xvi* + 183. *Illustrated. Index.* (*Chapman & Hall*, 1959.) Price 32s.

This book is unique in that it is the only one so far published in English that in its entirety deals with the theory and practice of impulse voltage testing. Its author has had an extensive experience of the subject, both as a research worker and an industrial engineer, so that he writes with authority and from first hand knowledge. He has, moreover, contributed papers on surge phenomena and testing which, in their day, advanced what was then known of the particular facets dealt with.

Impulse voltage testing is now an established industrial practice for electrical plant and certain apparatus (*e.g.* surge divertors), as is borne out by BS 116 : 1952, 171 : 1959, 923 : 1940, and 2914 : 1957 as well as by IEC publications. The present book is therefore very opportune, particularly as it provides guidance and instruction for those college courses in which testing practice can be linked with theory on the spot.

The book well covers all the necessary aspects of the subject, embracing definitions, impulse circuits, impulse generators, measurements and recordings, testing procedure, and the testing of plant and components. All of these are dealt with lucidly and with a maximum content of practical guidance such as one would expect from one who has actually done the work. Eight useful appendices are provided on related topics and there is a list of reference and the usual index. The book is well illustrated and it contains no more mathematics than is necessary for an understanding and appreciation of the requirements and behaviour of the circuits involved.

The author has done a first-rate piece of work in preparing this book; it will be found invaluable in research laboratories, in industrial test rooms, and in colleges having the necessary testing facilities. The volume belongs to the publisher's series of monographs on electrical engineering which was founded under the editorship of the late H P Young, whom many of us remember with affection. He would have liked this book.

S AUSTEN STIGANT

Elementary Matrix Algebra. *By Franz E Hohn.* $9\frac{1}{2} \times 6\frac{1}{4}$ *in* (241 × 159 *mm*). *Pp xi* + 305. *Index.* (*New York: Macmillan*, 1959.) Price 52s 6d net.

This book has been devised to be useful to a wide range of students in engineering, mathematics, the physical and chemical sciences and social science, and it contains the most essential material relating to the theory of matrices and determinants. The author is a professor of mathematics but in this work he has managed to avoid the welter of abstract argument that so often dismays workers in sciences other than pure mathematics, with the result that the book is a very attractive practical presentation of the subject.

The chapters embrace the following: introduction to matrix algebra, determinants, the inverse of a matrix, rank and equivalence, linear equations and linear dependence, vector spaces and linear transformations, unitary and orthogonal transformations, the characteristic equation of a matrix, and bilinear, quadratic, and hermitian forms. There are three appendices on, respectively, the notation Σ and Π, the algebra of complex numbers, and the general concept of isomorphism.

Numerous examples and exercises are provided and there is an excellent bibliography.

While no claim of complete coverage is made, the book will nevertheless be found to provide virtually all that is required by those needing to make practical use of matrix algebra up to quite a high level and it serves also as a good introductory text for students of mathematics. One's only regret is that it was not written thirty years earlier.

We recommend the book particularly to engineers and physicists with whom we are, perhaps, principally concerned in this Journal. The printing and general production of the work are both exceedingly good and well support the high standard of the text.

S AUSTEN STIGANT

Application of the Theory of Matrices. *By F R Gantmacher.* $9\frac{1}{4} \times 6\frac{1}{4}$ *in* (235 × 159 *mm*). *Pp ix* × 317. *Illustrated. Index.* (*London: Interscience Publishers Ltd*, 1959.) Price 63s.

This book is a pure mathematics text and it is applicational only in the sense of showing the use of matrix theory in other branches of mathematics. This statement is made solely to clarify the issue for the benefit of readers of this Journal, and no derogatory implication is contained in that 'only'. Indeed, for those engineers and applied mathematicians who are interested in matrix mathematics, the book is excellent.

By chapter headings the work covers complex symmetric, antisymmetric and orthogonal matrices; singular bundles of matrices; matrices with non-negative elements; applications of the theory of matrices to the study of systems of linear differential equations; and the Routh-Hurwitz problems and related questions. There are four brief appendices, an extensive bibliography and an index.

Reverting to applications, it may be pointed out that the translator (the original is in Russian) remarks that the chapters on the Routh-Hurwitz problem provide the theory needed by control engineers in studying the stability of servo-mechanisms, while the chapter on matrices with non-negative elements is useful in numerical analysis and engineering.

The translator has served his author exceptionally well in his work, which is of significant clarity. The printers and publishers have done their parts equally well by producing such an attractive format. The book is well recommended as a high quality test to the classes of readers already indicated.

S AUSTEN STIGANT

The Protection of 11 kV and 33 kV Bushings from Damage by Arcs in Still Air and in a Wind. *By A E Guile. Report No O/T20.* 11 × $8\frac{1}{2}$ *in.* (279 × 216 *mm*). *Pp* 12. (*London: The British Electrical and Allied Industries Research Association*, 1959.) Price 12s net.

The report describes the second stage in an experimental investigation carried out at Queen Mary College (University of London), to determine the effectiveness of

arcing devices in protecting high voltage insulators and bushing shields from damage in still air and in wind conditions.

The first stage of the investigation, which was concerned with the mechanism of arc movement between parallel horizontal rods under the influence of the magnetic field due to the current in the rods, and with the interaction of wind and magnetic forces, was described in Ref. O/T19.

Tests on an 11 kV bushing fitted with a single pair of arcing horns have shown that fracture of the porcelain can occur under various conditions, but that this can be avoided by fitting deflector rings and a second pair of horns in parallel with the first. In a similar way, it was shown that improved protection can be given to bushings fitted with duplex arcing horns. These results are applicable to larger insulators and assist the continuation of the investigation.

Heating of Cables. *By H Goldenberg.* $9\frac{7}{8} \times 7\frac{7}{8}$ *in* (250 × 200 *mm*). *Pp* 10. (*London: The British Electrical and Allied Industries Research Association*, 1959.) Price 7s 6d net.

The problem of the transient temperature rise due to a line source in a semi-infinite medium with a radiation boundary condition at an interface parallel to the line source, is the basic problem involved in the calculation of underground cable ratings for intermittent loads, and is solved in the present report. The deviation between this solution and the solution subject to an isothermal boundary condition at the interface is clearly specified. Neher's formula for the steady-state temperature is obtained as an approximation. An example is given showing the ratio of transient to steady-state temperature rise at the upper surface of a cable laid direct in the ground under each of the two assumed boundary conditions.

Aircraft Electrical Engineering. *Edited by G G Wakefield, AMIEE, AFRAeS. Pp* 349. $9\frac{3}{4} \times 6$ *in* (254 × 159 *mm*). 201 *line and half-tone illustrations.* (*Chapman and Hall, Ltd.*) Price 50s.

This is a type of textbook with which the reviewer is becoming increasingly familiar, a symposium of papers from leading authorities in the field with which the book is concerned. It is distilled from a series of lectures given at the Imperial College of Science and Technology in London by contributors who are active in the aircraft industry. It also carries the *cachet* of the Royal Aeronautical Society's general sponsorship.

In an introductory survey it is made clear that aircraft electrical equipment, with installed generating capacities on the largest aircraft reaching the astonishing figure of well over 250 kW, has now outgrown the 'light current engineering' classification, and takes its place in the heavy current category. The authors of the introductory survey indicate the vital aspects of the subject as they appear to-day: greater emphasis on the safeguarding of electrical supplies; the desirability of using constant frequency ac supplies and the attendant problems; and the difference of opinion which still exists as to the best form of prime mover—hydromechanical drive, air turbine, and small gas turbine.

The environmental conditions and functional requirements of aircraft electrical equipment are dealt with clearly yet exhaustively by M Hancock of the Royal Aircraft Establishment, and we then move on to one of the major problems of aircraft generators—excessive brush wear. R F Sims, who has prepared this chapter, describes the equipment developed at the RAE for high altitude brush testing, and he also draws largely on American experience.

Vibrational problems are briefly dealt with, and C S Hudson, also of the RAE, discusses the cooling of electrical machines for aircraft. There are then two chapters, written by B Adkins of Imperial College and W Philipp, of Rotax Ltd, on dc and ac machines respectively. Aircraft switchgear is dealt with by A Grieve, of BTH.

G A Earwicker, of the RAE, in his chapter on aircraft batteries, naturally deplores the lack of development in this field in regard to the evolution of new principles, although he pays tribute to the way in which structural design improvements in lead-acid batteries have made possible notable improvements in performance. Nevertheless, he stresses the need for more stable batteries and for better voltage regulation.

The chapter on electrical power systems in aircraft, prepared by J H Rea, of Rotax Ltd, tends to duplicate in many respects the arguments set out directly or by inference in the earlier chapters, but it none the less provides a neat conspectus of the various systems in use in modern aircraft.

Installation work is discussed by H Zeffert, of Vickers Armstrong (Aircraft) Ltd. He courageously criticizes the complex American cable coding system.

Another BTH engineer, K J Payne, deals with system operation and protection, and again one is compelled to mention the elements of duplication of material discussed in earlier chapters.

The chapter on future developments, which concludes the book, is a little disappointing, because its author, S F Follett, of the Ministry of Supply, does little but summarize the conclusions reached by the other authors.

The book does not contain any detailed references to the radio, radar, landing-aid, lighting (external and internal), or domestic service equipment of any sort of aircraft. It might be thought that a more severe pruning of the contents would have allowed for two useful chapters on electronic equipment and the other aspects of aircraft electrical engineering mentioned above.

J H M S

Garcke's Manual of Electricity Supply. $8\frac{1}{2} \times 6$ *in* (216 × 152 *mm*). *Pp xxxv* + 766. (*London: Electrical Press Ltd.*) Price 80s net.

Garcke is now in its 56th edition and is one of the most valuable reference books in the electricity supply industry in the United Kingdom. The present volume follows the pattern of previous years and contains statistical and operational details of the Electricity Council, The Central Electricity Generating Board, the Scottish, Northern Ireland, and Channel Islands electricity undertakings.

A chapter is included which gives the latest information on the United Kingdom nuclear power programme, and details of the five nuclear power construction groups and the UK Atomic Energy Authority.

Electrical and allied manufacturers are dealt with in a separate section which includes background information, issued capital and the names of the directors.

Institutions, trade associations, national and representative bodies concerned with industrial relations, research, and trade are also listed, with a short account of their activities. There is also an alphabetical list of senior and executive personnel in the electrical supply and manufacturing industries.

Practical Electrician's Pocket Book. *Edited by R C Norris.* $5\frac{1}{4} \times 4$ *in* (133 × 102 *mm*). *Pp* 536. (*London: Odhams Press Ltd*, 1960.) Price 7s 6d net.

This popular hand book is now in its sixty-second year, making it one of the oldest of its kind still in regular publication. The 1960 edition has several new and revised chapters, and some of the additional subjects introduced are refrigerators, public address, education in the electrical contracting industry, and tariffs.

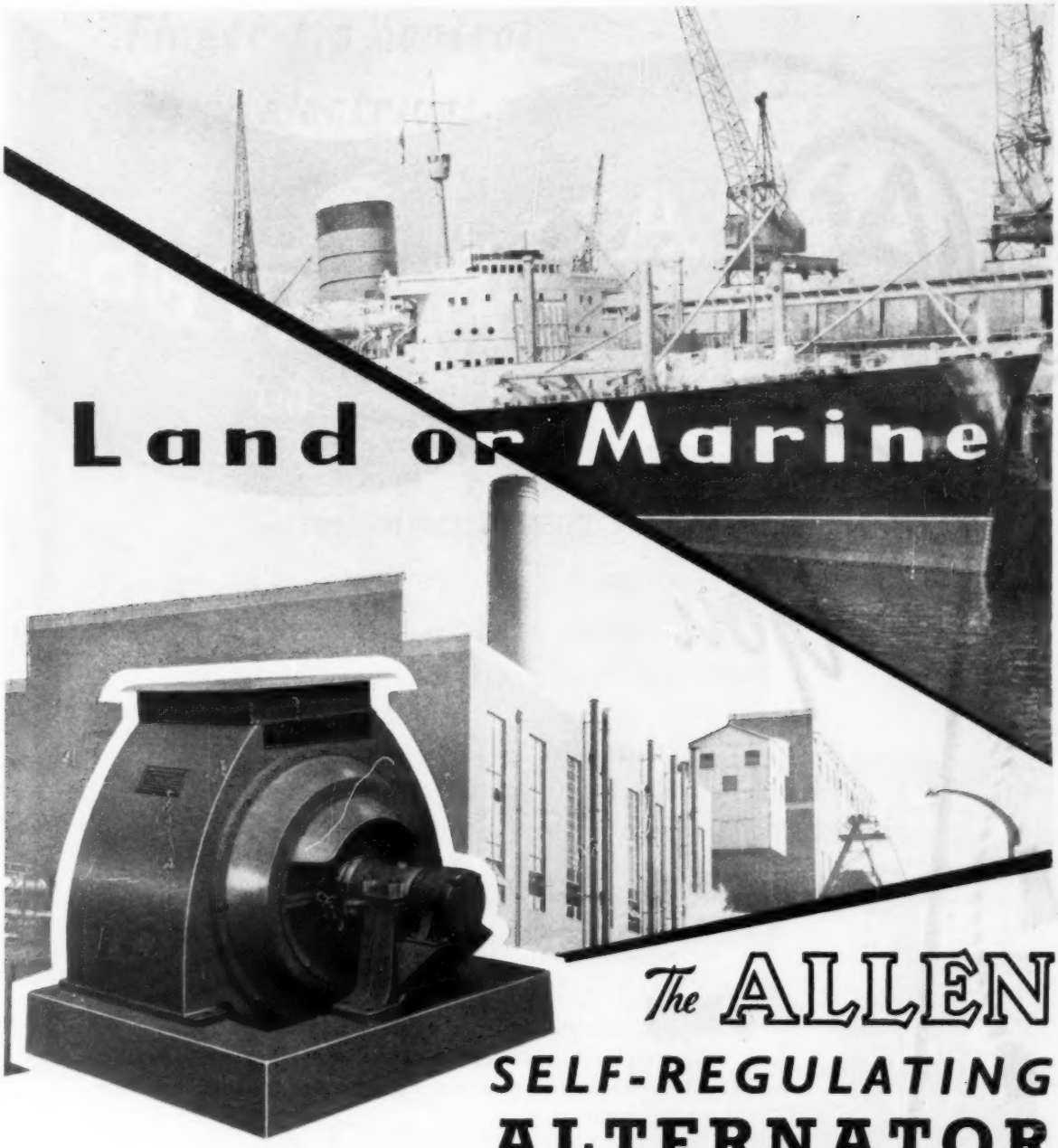
The principles and operation of both the compressor and absorption type of refrigerators are discussed and some hints and tips on fault finding are included. The former chapter on accumulators has been revised and expanded and given the new title of 'Storage Batteries'. A new chapter describes the characteristics and uses of germanium and silicon power rectifiers and similar electronic devices. A number of chapters has been revised and expanded to give more details of floor warming, earthing, power factor correction, and instruments. Other chapters of particular interest are those on domestic appliance repairs (first introduced in the last edition), electric motors and machine tool control equipment. The book is a veritable mine of information and will prove invaluable to every electrician.

British Plastics Year Book, 1959. $9\frac{1}{2} \times 6\frac{5}{8}$ *in* (241 × 168 *mm*). *Pp* 644. (*London: Iliffe & Sons Ltd.*) Price 42s net.

First published in 1931, this year book is full of information on the British plastics industry. A general section contains a glossary of technical terms, a tabulation of properties of plastic materials, new companies and a list of British Specifications. Classified lists of raw materials, manufactured products, and plant used and produced by the plastics industry is included, with names and addresses of manufacturers and a list of trade marks. The book also includes a 'Who's Who' in the plastics industry. The section devoted to abstracts of patents has been discontinued, as this service is now available through the British Plastics Federation.

Index to Advertisers

	Page
Allen, W. H., Sons & Co., Ltd.	1
Allen West & Co., Ltd.	2
Arrol, Sir Wm., & Co., Ltd.	4
Associated Electrical Industries Ltd.	
Motor & Control Gear Division	3
Turbine Generator Division	5
Cable Division	6
Babcock & Wilcox Ltd.	8
Belliss & Morcom Ltd.	7
Berry's Electric Ltd.	10
Bolton, Thos., & Sons Ltd.	14
British Insulated Callender's Cables Ltd.	9
British Overseas Airways Corporation	11
Brookhirst Igranic Ltd.	12
Bushing & Co., Ltd.	13
Chloride Batteries Ltd.	23
Davidson & Co., Ltd.	15
Donovan Electrical Co., Ltd., The	14
Drysdale & Co., Ltd.	16
EMI Electronics Ltd.	17
EMI Sales & Service Ltd.	18
Ellison, George, Ltd.	Back Cover
English Electric Co., Ltd.	19
Erskine Heap & Co., Ltd.	21
Evershed & Vignoles Ltd.	20
Ferranti Ltd.	Inside Cover
Formica Ltd.	22
GWB Furnaces Ltd.	26
General Electric Co., Ltd., The	24-25
Hackbridge & Hewittic Electric Co., Ltd.	27
Heatrae Ltd.	28
Heenan & Froude Ltd.	23
Hick Hargreaves & Co., Ltd.	35
Invicta Electrodes Ltd.	29
Lincoln Electric Co., Ltd.	30
MK Electric Ltd.	31
Mather & Platt Ltd.	32
Mawdsley's Ltd.	33
Micanite & Insulators Co., Ltd.	34
Mirrlees Watson Co., Ltd., The	35
Nalder Bros. & Thompson Ltd.	36
Newton Bros. (Derby) Ltd.	43
P. & B. Engineering Co., Ltd.	37
Parsons, C. A., & Co., Ltd.	38
Permali Ltd.	39
Philips Electrical Ltd.	40
Pilkington Bros. Ltd.	41
Pinchin Johnson & Co., Ltd.	42
Premier Cooler & Engineering Co., Ltd., The	43
Reyrolle, A., & Co., Ltd.	44
Richardsons, Westgarth (Hartlepool) Ltd.	45
Sangamo Weston Ltd.	46
Simplex Electric Co., Ltd.	47
Smith, Frederick, & Co.	48
Standard Telephones & Cables Ltd.	49
Sterling Varnish Co., Ltd., The	50
Thomas, Richard, & Baldwins Ltd.	51
Van Nostrand, D., & Co., Ltd.	Inset
Yorkshire Electric Transformer Co., Ltd.	52



Land or Marine

The ALLEN SELF-REGULATING ALTERNATOR

- Completely static excitation and control system; no d.c. exciter, no relays or contactors.
- Steady-state accuracy independent of power factor or temperature; static automatic trimming control.
- Superior transient voltage performance: line-current compounding halves voltage dips and provides rapid response.
- Positive and reliable excitation initiation system: permanently-connected yet independent of alternator residual magnetism.

W. H. ALLEN SONS & Co LTD BEDFORD

FIFTY YEARS OF CONTROL GEAR DEVELOPMENT

You **have made possible a notable half-century of achievement . . .**

To you, our Customers throughout Great Britain and overseas, we offer a special Golden Jubilee 'Thank You'. Your support and co-operation during these eventful years have

- Stimulated development of new Allen West techniques and resources to meet the ever-advancing demands of Industry, Electrical Traction and Marine Service
- Helped us from modest beginnings in 1910 to become the biggest organisation in the British Commonwealth specialising in the manufacture of electric motor control gear
- Enabled us to maintain, in terms of improved efficiency and service, our proud claim that for every electric motor, however arduous or intricate the application, there is an Allen West starter

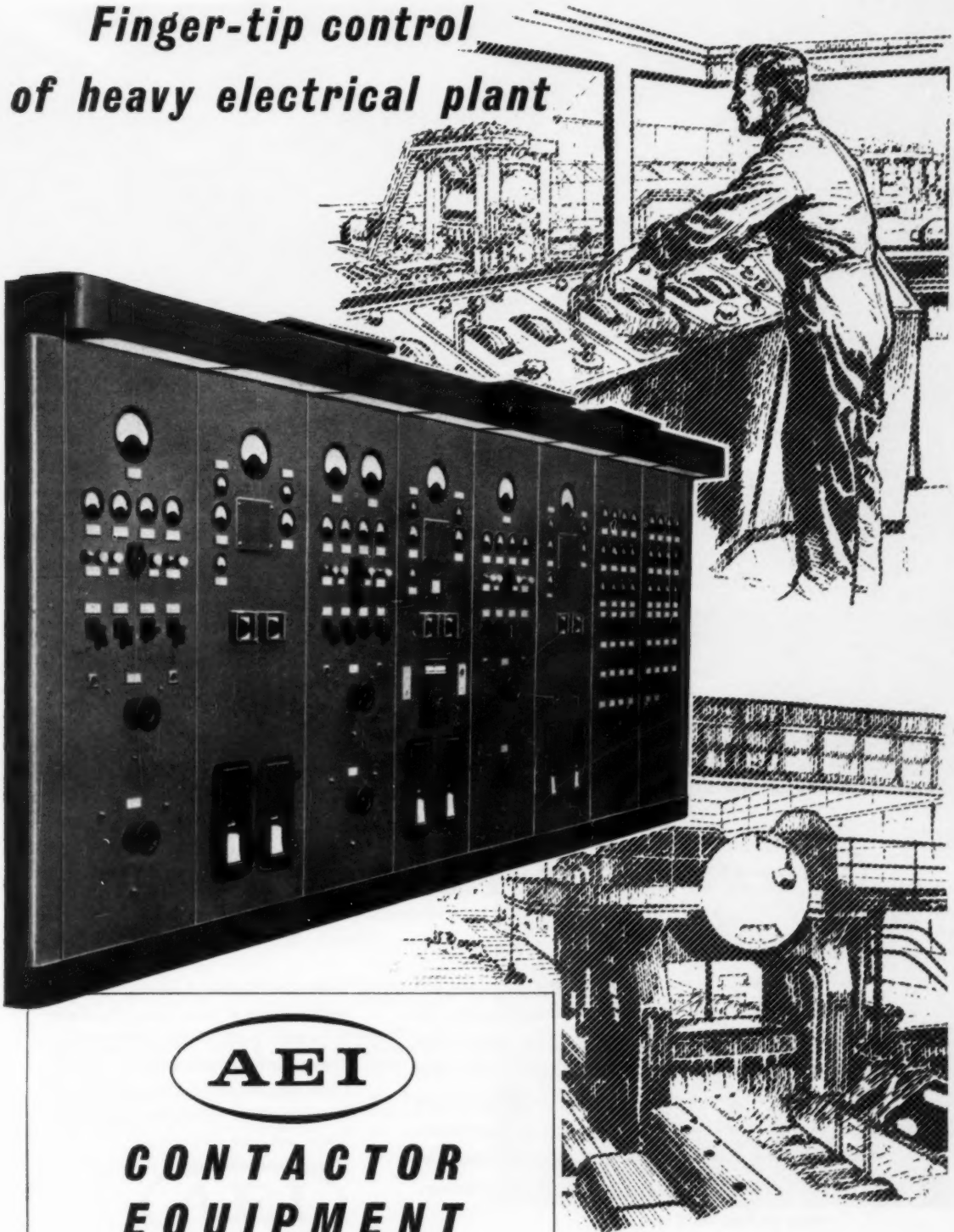
In the challenging years ahead, your needs will ever be our interest

ALLEN WEST & CO LTD

BRIGHTON · ENGLAND

SUBSIDIARY COMPANIES IN CANADA, SOUTH AFRICA & RHODESIA · AGENCIES THROUGHOUT THE WORLD

Finger-tip control of heavy electrical plant



AEI

CONTACTOR EQUIPMENT

ASSOCIATED ELECTRICAL INDUSTRIES LIMITED

MOTOR & CONTROL GEAR DIVISION — **RUGBY & MANCHESTER, ENGLAND**

INCORPORATING THE MOTOR & CONTROL GEAR INTERESTS OF BTH & M-V

A5501

Cranes for Power Houses

The diverse resources of ARROL continue to play a vital part in maintaining Britain's power supply. Their skill is symbolised in the structural steel work of many major projects and in such powerhouse cranes as that illustrated here—100 ton capacity crane at Prince Dock Generating Station 'B', Plymouth. Similar cranes have been constructed up to a capacity of 260 tons for installations in many parts of the world and in addition a considerable number of cranes of 200 tons capacity have been constructed for the works of transformer and generating equipment manufacturers.

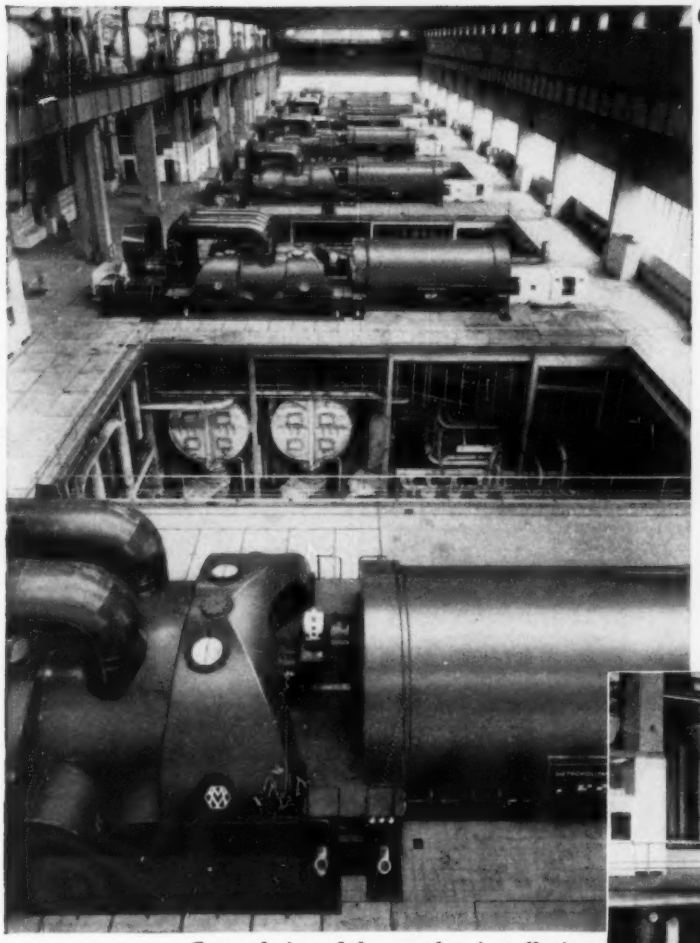
Cranes and Mechanical Engineering work; all types of Steel Framed Buildings; Fixed and Opening Bridges; Dock Gates; Sliding and Floating Caissons; Compressed Air Locks; Hydraulic Machinery; Pipe Lines, Surge Tanks, Sluices and other equipment for Hydro-Electric Projects.

SIR WILLIAM ARROL & CO LTD GLASGOW

Arrol

CASTLE DONINGTON

C.E.G.B. East Midlands Division.



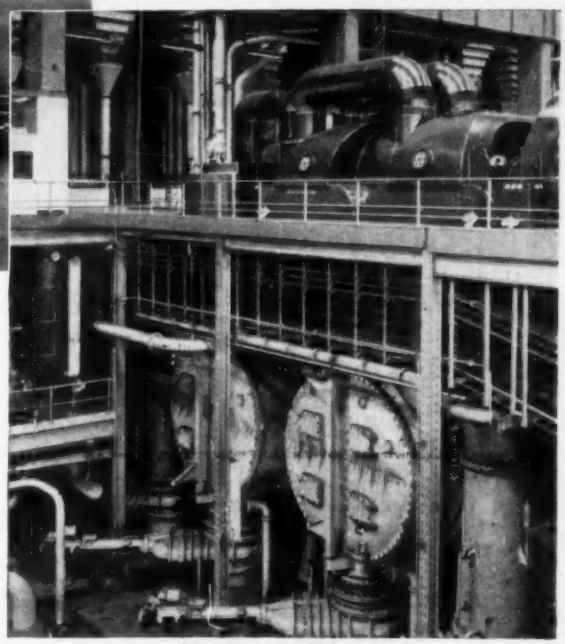
General view of the complete installation of six 100 MW turbine-generators

The largest single thermal power station in Western Europe

Castle Donington houses six 100 MW 3000 rpm steam turbine-generators together with their associated condensing plants and feedwater heating equipments. All this power plant was manufactured by A.E.I. Turbine-Generator Division.

Castle Donington recorded the highest average overall thermal efficiency of any British power station during the three years ending 31st March 1959.

The two-cylinder, close-coupled turbines operate with steam conditions at the turbine stop valve of 1500 psig, 1050 F and exhaust to A.E.I. condensers.
Direct-coupled generators produce 3 phase, 50 c/s alternating current at 13·8 kV. The rotor windings are directly cooled by hydrogen circulating in contact with the copper.
The generators are directly connected to the A.E.I. main step up transformers and the power is controlled to the grid by A.E.I. circuit-breakers.



No. 2 set and its twin-shell A.E.I. Condenser.

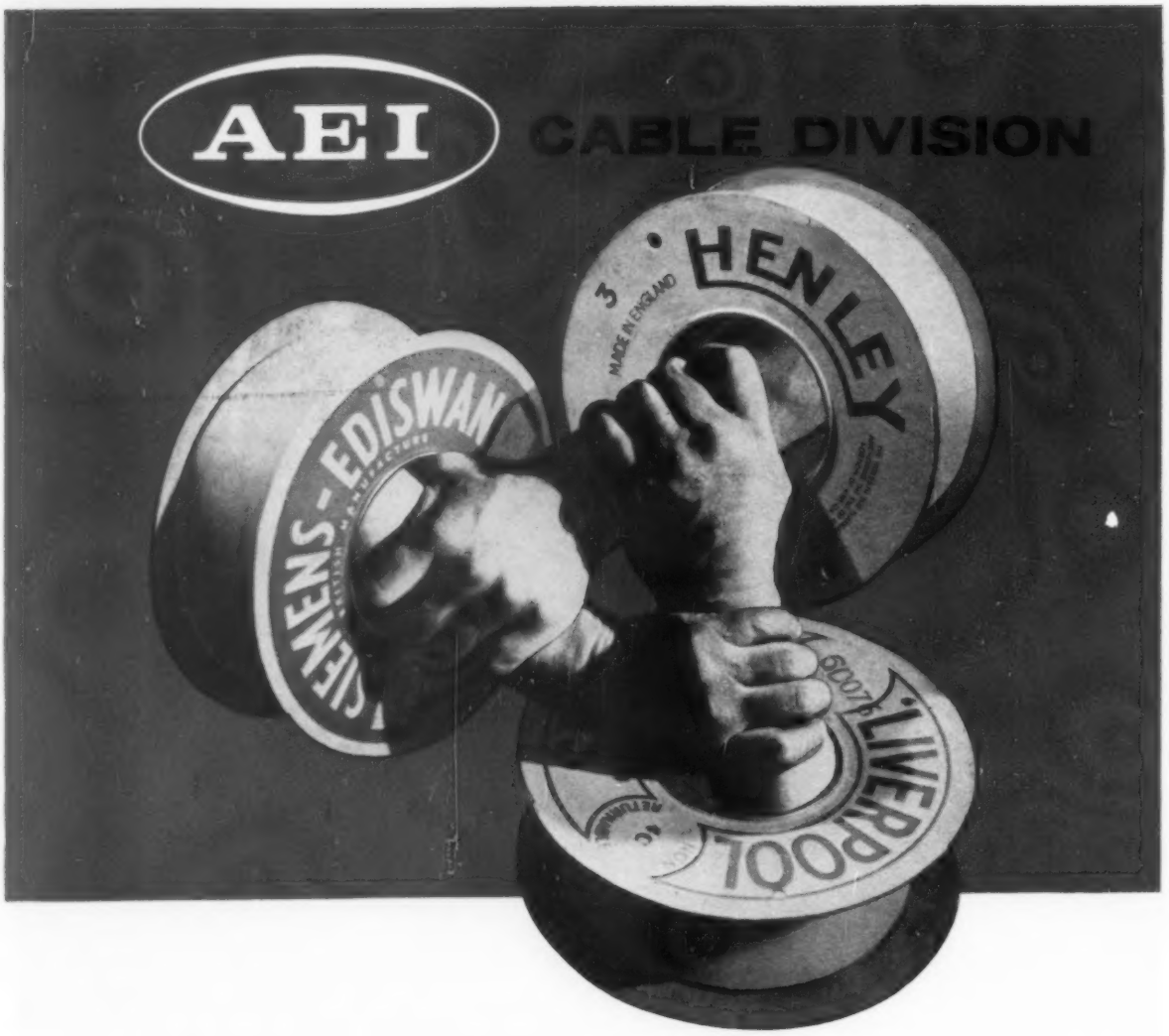
AEI

Associated Electrical Industries Limited

TURBINE-GENERATOR DIVISION

Enquiries to: A.E.I. Turbine-Generator Division; Trafford Park, Manchester 17, or to your local A.E.I. office.

WORKS AT MANCHESTER AND RUGBY, ENGLAND · GLASGOW SCOTLAND · LARNE NORTHERN IRELAND



Unites the resources of three great companies

HENLEY CABLES

LIVERPOOL CABLES

SIEMENS EDISWAN

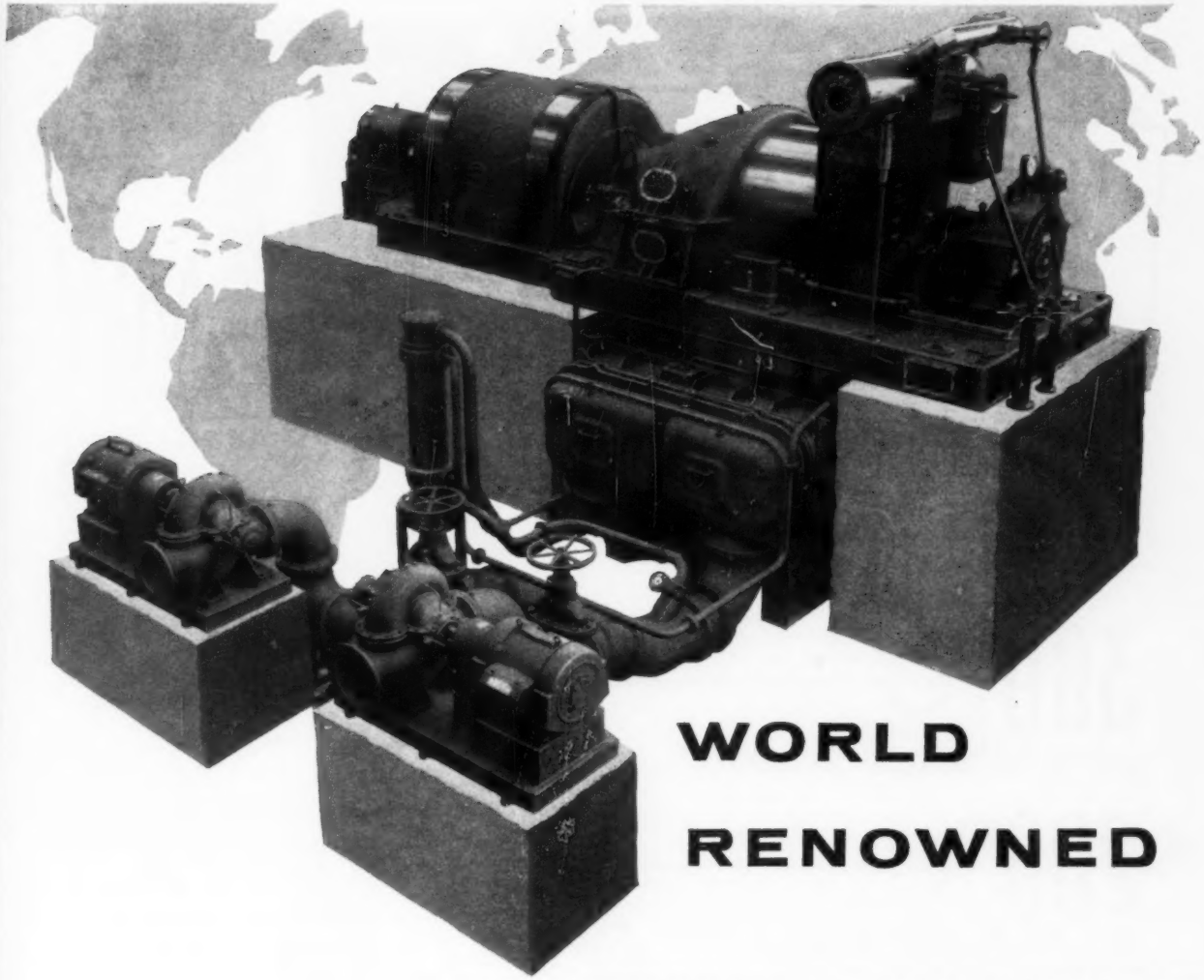
Three names having a long and honoured history in the manufacture and supply of every kind of wire and cable known to the Electrical Industry. Now, their resources, know-how, and manufacturing capacity are multiplied together to create something much greater than the sum of their individual facilities. Behind them the massive organisation of AEI will assure a steady flow of the latest technical data. There is no cable requirement too new, too big, too complicated, for this powerful and effective combination. By the same token, no order for ordinary small wires and cables is too small to have their ready and instant co-operation.

AEI

CABLE DIVISION

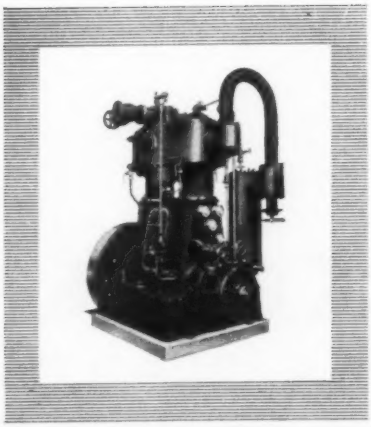
Associated Electrical Industries Limited

31-69 Hatton Garden • London • E.C.1 • Phone: CHancery 6922



WORLD RENOWNED

STEAM TURBINES & STEAM ENGINES



Steam Engine utilizing heating or process steam.

Belliss & Morcom are world-renowned for precision engineering.
The 6000 kW B & M Passout Condensing Turbo Alternator
is seen erected in the works before shipment to the U.S.S.R.
The compact one-floor arrangement is unique
for this size plant.

STEAM TURBINES up to 15,000 kW
STEAM ENGINES up to 900 b.h.p.
COMPRESSORS HIGH and LOW PRESSURE
DIESEL ENGINES 120 to 2,000 b.h.p.
DUAL FUEL ENGINES
CONDENSING PLANTS
VACUUM PUMPS over 30 M^3 SWEPT VOLUME.

Belliss & Morcom Ltd

BIRMINGHAM 16 · ENGLAND

THE WORLD'S LARGEST SINGLE-FURNACE NATURAL-CIRCULATION BOILER

550 MW

Babcock Radiant, reheat type, pulverized-fuel-fired, with an evaporation of 3,750,000 lb./hr. at 2400 lb./sq. in. 1055 F, for THORPE MARSH power station, Central Electricity Generating Board.

300 MW

Radiant, reheat units, pulverized-fuel-fired, for WEST THURROCK power station.

200 MW

Radiant, reheat units, pulverized-fuel-fired, for WEST THURROCK, WILLINGTON 'B', KINCARDINE and HAZELWOOD (Australia) power stations.

100 MW TO 120

Radiant units (four with reheat) pulverized-fuel or 'Cyclone' fired, of capacities from 100 to 120 MW, for BLYTH 'A', RUGELEY, USKMOUTH 'B', PADIHAM 'B', FERRYBRIDGE 'B', ASNAES (Denmark), PONT BRULE (Belgium); and also the six 100 MW units at CASTLE DONINGTON power station, which topped the efficiency table in 1959.

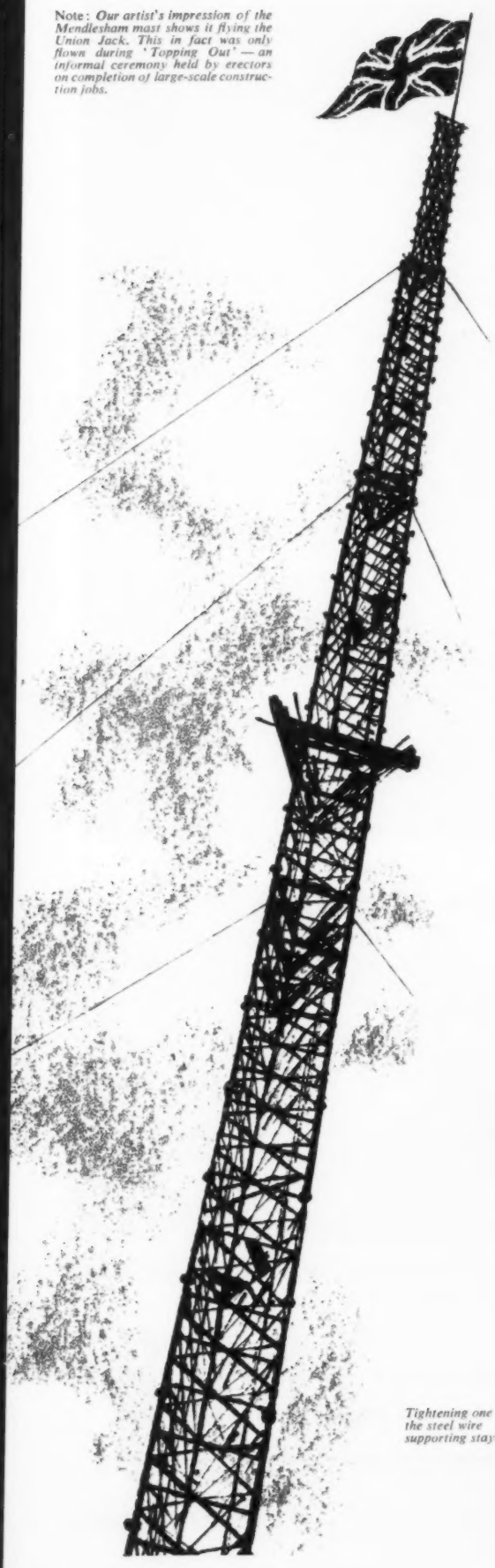
Central station boiler development in recent years has been remarkable for the steep rise in unit capacities, with parallel advances in steam conditions and the extensive use of reheat; achieving valuable gains in thermal efficiency. This development reflects intensive progress—in design, engineering and manufacture—by the BABCOCK organization, which has supplied, or is currently manufacturing, a considerable number of boilers of from 100 to 300 MW capacity, and which is now to supply a unit of 550 MW capacity—the first to provide this huge output from a single-furnace natural-circulation design.

BABCOCK

STEAM-RAISING PLANT

BABCOCK & WILCOX LTD., BABCOCK HOUSE, 209 EUSTON ROAD, N.W.1

Note: *Our artist's impression of the Mendlesham mast shows it flying the Union Jack. This in fact was only flown during 'Topping Out' — an informal ceremony held by erectors on completion of large-scale construction jobs.*



ONE THOUSAND FEET UP

AT MENDLESHAM!

On the 27th October High Power Transmission from the Mendlesham mast commenced. Over one million televiewers will now be able to receive a first-class service from the I.T.A. Station.

A thousand feet high, this mast is the tallest structure in Great Britain, yet it is only 8′ 6″ across each side of its triangular framework.

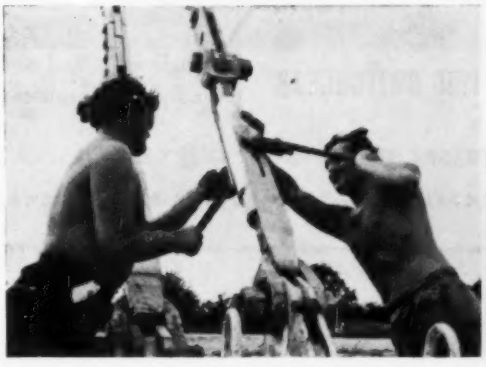
It was built in *ten weeks* to the requirements of I.T.A. and their main contractors, E.M.I. Electronics Ltd. The design and erection were undertaken by BIC Construction Company and the steelwork was fabricated and galvanised by Painter Bros. of Hereford — both members of the BICC Group.

Other transmitting masts and towers supplied by BICC include those at :—

CRYSTAL PALACE (London)
CHILLERTON DOWN (Isle of Wight)
SUTTON COLDFIELD (Birmingham)
BURNHOPE (Co. Durham)
HOLME MOSS (Huddersfield)
BLACK MOUNTAIN (Belfast)
KIRK O' SHOTTS (Lanarkshire)
DOVER (Kent)
BLACK HILL (Lanarkshire)
ST. HILARY (nr. Cardiff)

BICC GROUP

BRITISH INSULATED CALLENDER'S CABLES LIMITED
21 BLOOMSBURY STREET LONDON WC1



Tightening one of the steel wire supporting stays

Base of 1,000 ft. transmission mast

From Berry's come the best

ELECTRIC FIRES	Magicoal and Berrylog—all the comfort of an open fire at the touch of a switch!
ELECTRIC LIGHT FITTINGS	period and contemporary designs in glass, metal, wood and fabric
ELECTRIC WATER HEATERS	in all standard types and sizes from 1½ to 20 gallons
ELECTRIC SWITCHGEAR	single units and complete boards for all industrial purposes

BERRY'S ELECTRIC LTD · TOUCHBUTTON HOUSE · NEWMAN STREET · LONDON W1 · MUSeum 6800

"Here are 5 ways BOAC Air Cargo can help your business!"

We deliver your goods in *hours*, instead of days or weeks! And that's only one of the things you gain. Speed alone may not be enough for you—but BOAC Air Cargo gives other advantages that benefit *every* business . . .

- BOAC's fast modern airliners make unprofitable 'time in transit' hours shorter.
- Goods go direct from city to city by BOAC—without slow journeys to and from the docks.
- BOAC gives all goods careful, skilful handling . . . so packing can be simpler and cheaper.
- Goods get individual attention all the way, by BOAC.
- Because of BOAC's fine record of safe handling and security, insurance costs are lower and coverage is wider.

More and more successful businessmen are getting these 5 extra advantages from BOAC Air Cargo . . . advantages that can help *your* business! Ask for details now—from your BOAC Appointed Shipping and Forwarding Agent or ring BOAC and ask for "Skyload" Service Unit.

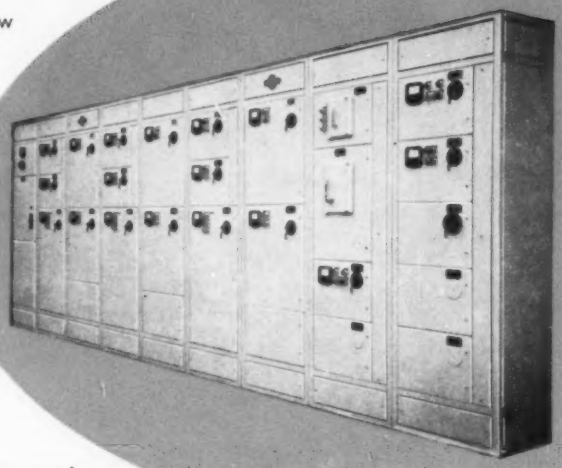
B·O·A·C gives your cargo jet-age handling

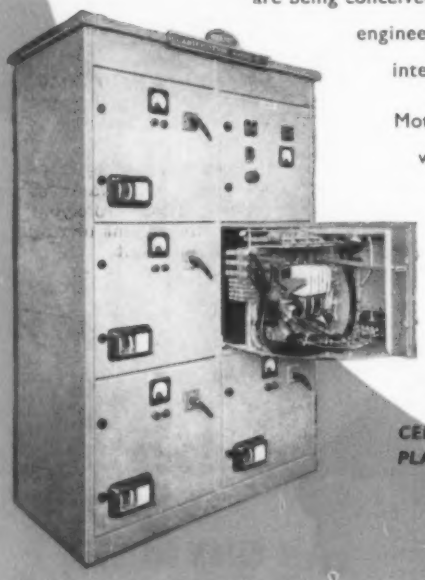
BRITISH OVERSEAS AIRWAYS CORPORATION

Controlling the flow

Production must flow in a steady stream . . . from material and component stock, through machinery or processing, to the finished stage.

The conveyors that speed this stream, the machines it feeds, the processing plant through which it passes . . . these, and the many main or ancillary equipments that serve the flow, are being conceived by today's engineers as studies in grouped or integrated control.





Motor control centres by Brookhirst Igranic, who give consultant service on control problems, are integrally reliable, easy to install and maintain, with easily interchangeable units, and easily modified or extended.

CENTRALISED, STANDARDISED PLANT & PROCESS CONTROL with Brookhirst Igranic motor control centres

BHI

Metal Industries Group

BROOKHIRST IGRANIC LIMITED

Sales Headquarters: BEDFORD WORKS · BEDFORD · *Works at:* BEDFORD & CHESTER

Area Offices: Birmingham Bristol Cardiff East Anglia Glasgow Leeds London Manchester Mid-Southern Newcastle Nottingham Sheffield Belfast

Britain's biggest maker of electrical control and associated equipment

STANDARD CAPACITORS

The Bushing Co. Ltd. manufactures a range of compressed gas capacitors intended for use as comparison standards for the measurement of capacitance and dielectric loss factor. The capacitors are constant in value and virtually loss-free.

The gaseous insulant is dry, oxygen-free nitrogen at a pressure of 10 atmospheres and freedom from losses and invariance of capacity is ensured by the design and screening of the electrodes.

The sizes available range from 50k V to 500k V and both 50pF and 100pF capacitors are available in each size.

THE BUSHING COMPANY LTD.
HEBBURN-ON-TYNE, ENGLAND

Telephone: HEBBURN 83-2241
Grams: "BUSHING HEBBURN"

TEXOLEX
THE BUSHING CO. LTD.
HEBBURN-ON-TYNE

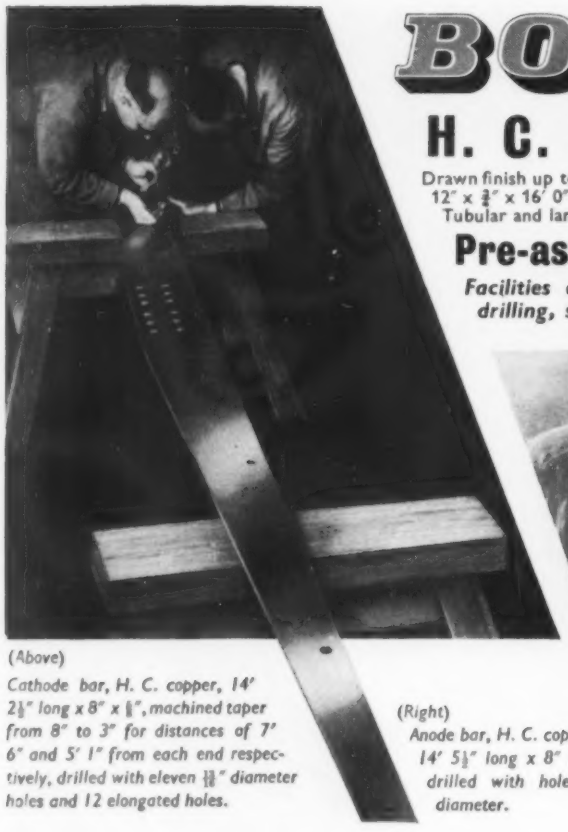
BOLTON'S

H. C. COPPER BUSBARS

Drawn finish up to 3" square or to 10" wide x 1" thick; hard rolled up to 12" x ¾" x 16' 0" long. Extra heavy machined bars to customers' requirements. Tubular and laminated busbars.

Pre-assembly work on copper busbars

Facilities are available in our Works for bending, sawing, drilling, slotting, and tinning to customers' requirements.



(Above)
Cathode bar, H. C. copper, 14' 2½" long x 8" x ⅝", machined taper from 8" to 3" for distances of 7' 6" and 5' 1" from each end respectively, drilled with eleven ⅞" diameter holes and 12 elongated holes.

(Right)
Anode bar, H. C. copper, 14' 5½" long x 8" x ⅝" drilled with holes ⅞" diameter.

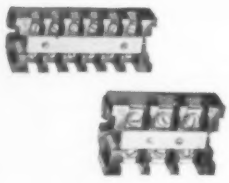
THOMAS BOLTON & SONS LTD

Head Office:
Mersey Copper Works,
Widnes, Lancashire
Telephone: Widnes 2022

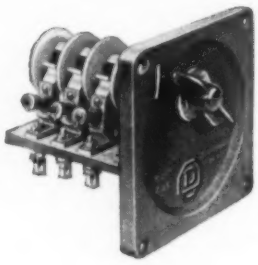
London Office and Export Sales Department:
168 Regent Street, W.1
Telephone: Regent 6427
Cables: Wiredrawn, London

Established 1783

Limit Switches (Type C32L 810/1) Plunger pattern with roller on end. Roller can be moved through 90 degrees and the switch can be altered from N.O. to N.C. on site.



Terminal Blocks (Type J96). Clamp type terminals. White marker strip, generous clearances between phases and to earth. Sizes available—15-amp. 550-volt. 3, 4, and 6-way. 30-amp. 550-volt. 3 and 4-way.



Flush-mounting T.P. Isolating Switch (Type C95) for building-in Machine Tools, etc. 30-amp. 550-volt.

a selection from a large range of

control accessories

by DONOVAN

THE DONOVAN ELECTRICAL CO. LTD.
GRANVILLE STREET . BIRMINGHAM 1

London Depot: 149-151 York Way, N.7

Glasgow Depot: 22 Pitt Street, C.2

A.C. Power Relays (Type A 11). Available 2, 4, or 8-pole (with one or two coil circuit change-over contacts), fine silver double-break main contacts rated at 10-amp. 550-volt. Any pole can be N.O. or N.C.

Illustrated is a 4-pole enclosed relay.

First Steps

First steps are important in all walks of life, as this fox cub emerging from his parental "earth" is already instinctively aware. And if he takes the wrong turning he can land up in serious trouble.

In fan engineering, as in nature, the choice of the better alternative is rarely an easy one to make.

If you have in mind an application involving the movement of air or other gases, the name "Sirocco" is synonymous with a great deal of hard won experience that is freely yours for the asking.

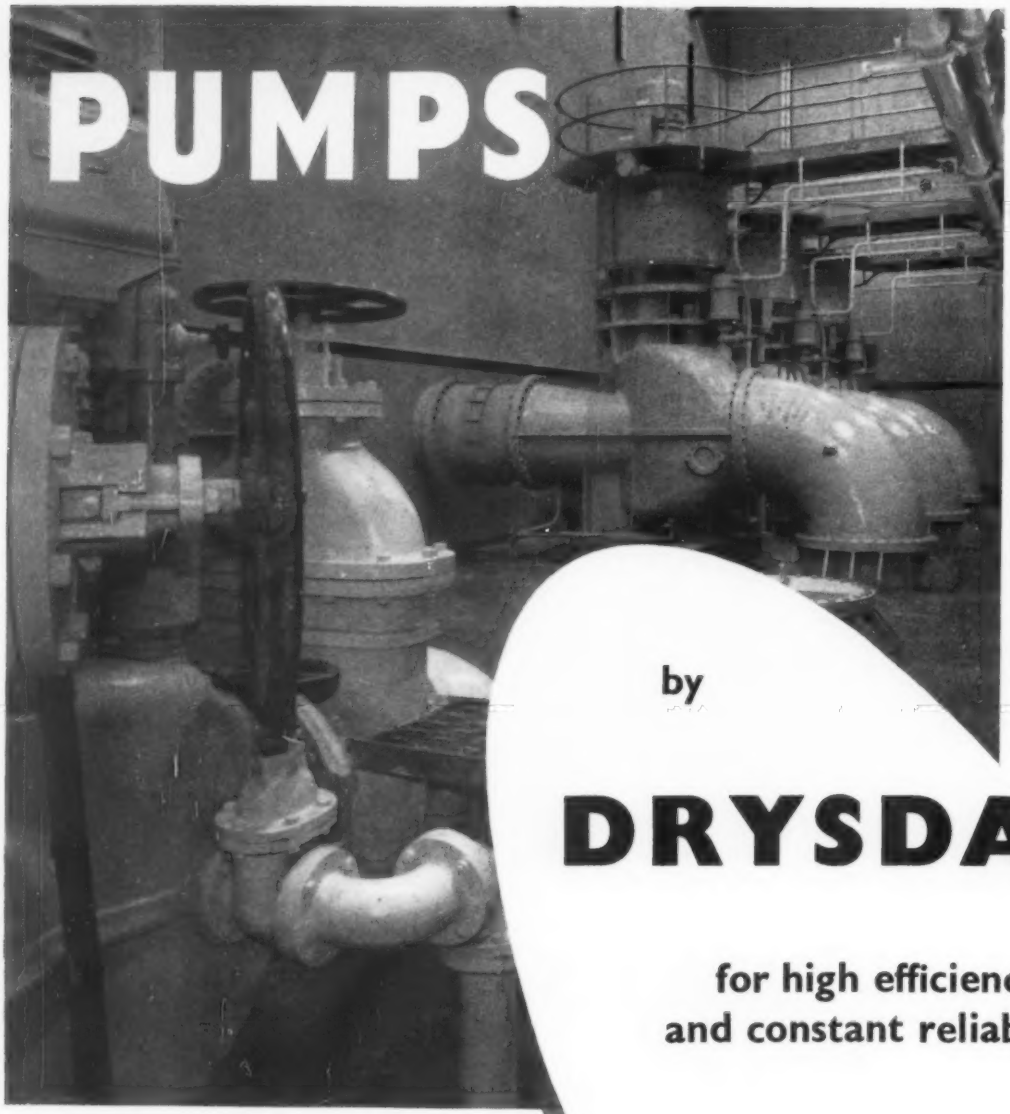
You are invited, as a first step, to take advantage of our 75 years of experience and our unrivalled design, manufacturing and testing resources by contacting our nearest Branch.

Our Works trained engineers are at your service.

DAVIDSON & CO. LTD.

SIROCCO ENGINEERING WORKS
BELFAST, NORTHERN IRELAND (*Belfast 57251*)

London (*Whitehall 3541*) · *Manchester* (*Blackfriars 6210*) · *Glasgow* (*City 6786*) · *Birmingham* (*Midland 4916*) · *Newcastle-on-Tyne* (*26584*) · *Leeds* (*21886*)



by

DRYSDALE

for high efficiency and constant reliability

Service before sales

After sales service

Our Research and Development department is constantly engaged on applied research in Fluid Mechanics and other branches of engineering science.

In addition every facility is available for the experimental investigation of problems directly concerning any specific pumping application. A fund of experience is available for customers' information ensuring the most efficient and economical pumping service.

After sales service is an important function of the Drysdale organisation. An active staff of service engineers and technical representatives is available for short notice, free advice, on the spot service, to ensure Drysdale auxiliaries operate at peak performance.

DRYSDALE & Co Ltd
YOKER : GLASGOW

PUMP MAKERS FOR LAND AND MARINE SERVICES FOR OVER 85 YEARS

Driverless trolleys following wires laid on or under the floor, controlled from a central point — that's the E.M.I. Robotug system. Recently developed by E.M.I. engineers as a further aid to automation, the system has widespread applications in warehouses, airports, parcels offices and other goods handling centres, where it can increase efficiency and cut costs. Highly flexible, the system enables any number of trolleys to be operated over routes which can be rapidly varied to meet new needs. The electronic control equipment is robustly constructed to withstand heavy industrial use. Transistors are employed throughout to give utmost reliability and minimum drain on battery power supply. A foolproof safety device ensures that the Robotug is automatically halted immediately it comes into contact with an object or person in its path.

The Robotug - one of E.M.I.'s automatic control systems

E.M.I. also designs and manufactures automatic control systems for:
** Milling machines, lathes, grinders, boring and drilling machines * Conveyor belt route selection, and sorting * Formula mixing and batch weighing * Data recording and analysing * Electric motor Commutator Undercutting machines * Armature Testing and Dynamic Balancing machines * Vibration and environmental testing.*

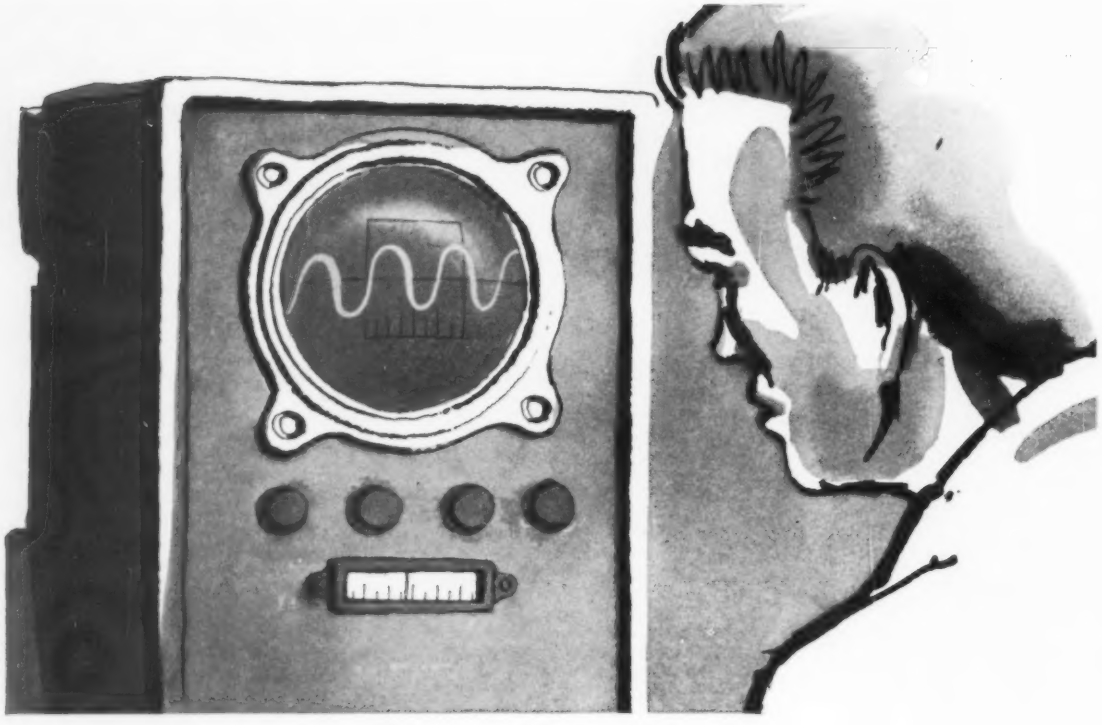
EMI

Please ask for full details, or a demonstration of any of these systems

E.M.I. ELECTRONICS LTD.

INDUSTRIAL DIVISION · HAYES · MIDDLESEX · TELEPHONE: SOUTHALL 2468

EE 51



Keeping an exact record—on tape . . .

Today the tape recorder can play just as vital a role in the research laboratory as in the recording studio... For it can provide an exact and continuous record on tape of electrical impulses or variations. For example—in vibration and shock testing, process and machine control, noise measurement, accurate recording of instrument readings—and scores of similar applications. For these purposes the major industrial and scientific organisations throughout the world choose EMI tape recording equipment—because it is specially designed to meet the most exacting demands of scientific work and offers the highest standards of quality and reliability in recording. And, of course, it has the big advantage of EMI's own unique experience in research behind it.

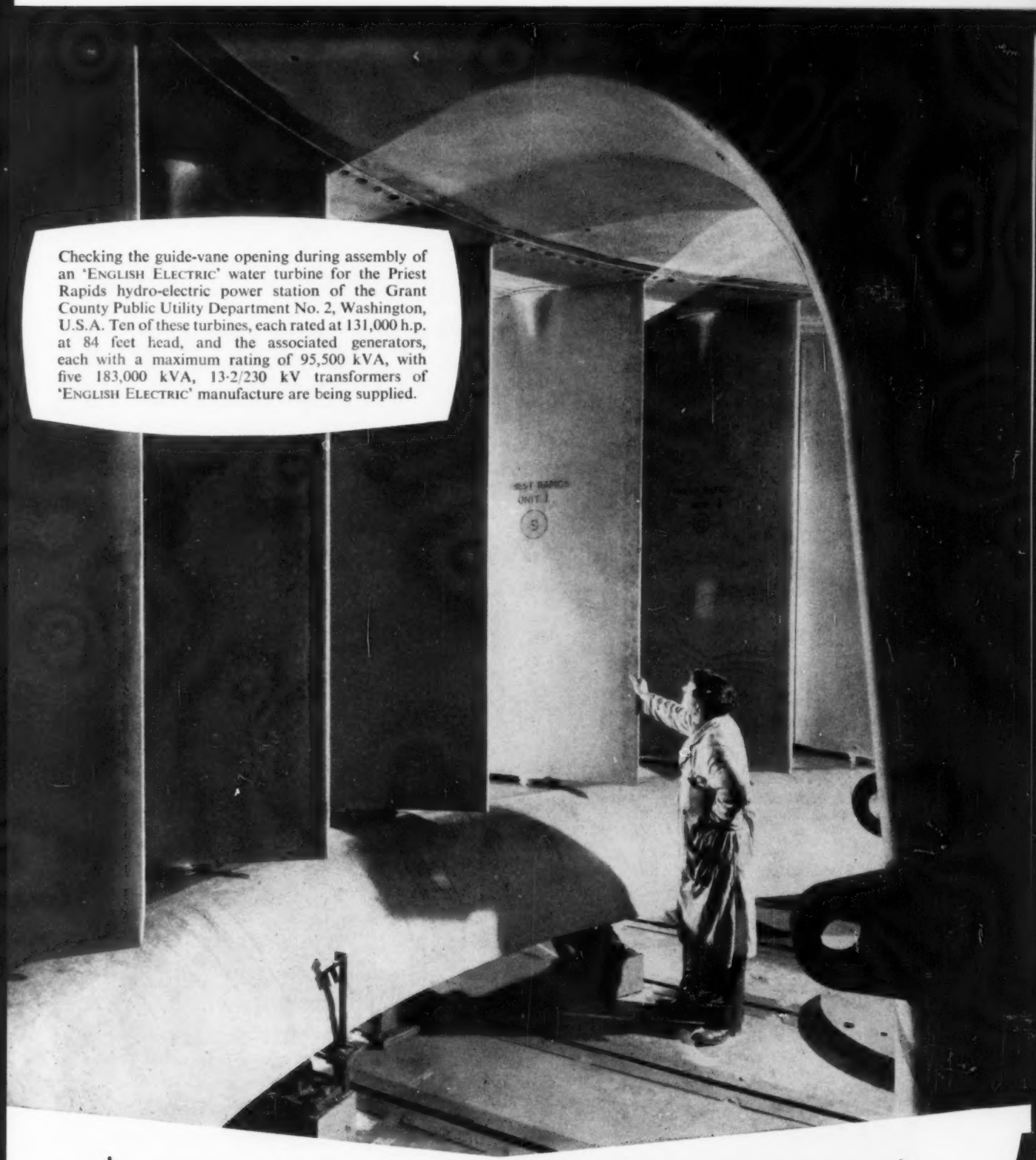
MODEL TR52/2D/H 15 ips & 7½ ips
MODEL TR52/2C/H 7½ ips & 3¾ ips
A convenient transportable stereo twin channel model offering the highest recording standards in completely mobile form.

EMI

For full details of EMI tape recording equipment, telephone or write to:

THE GRAMOPHONE COMPANY LTD
(Recording & Relay Equipment Division)
HAYES · MIDDLESEX · Tel: SOUthall 2468
(One of the EMI Group of Companies)

63/P/17



Checking the guide-vane opening during assembly of an 'ENGLISH ELECTRIC' water turbine for the Priest Rapids hydro-electric power station of the Grant County Public Utility Department No. 2, Washington, U.S.A. Ten of these turbines, each rated at 131,000 h.p. at 84 feet head, and the associated generators, each with a maximum rating of 95,500 kVA, with five 183,000 kVA, 13·2/230 kV transformers of 'ENGLISH ELECTRIC' manufacture are being supplied.

'ENGLISH ELECTRIC'

Power generation · Power transmission · Power control · Power distribution
Power transformation · Power conversion · Power utilisation · Power measurement

Power is our Business

THE ENGLISH ELECTRIC COMPANY LIMITED, MARCONI HOUSE, STRAND, LONDON, W.C.2

Partners in Progress with NAPIER, MARCONI'S, VULCAN FOUNDRY and ROBERT STEPHENSON & HAWTHORNS
in The ENGLISH ELECTRIC Group

A famous family

MEGGER

TRADE MARK

Illustrated are four examples from the Megger family of insulation testers.

A & B. Heavy duty Series 1 testers in hard wood cases. Hand driven or mains operated.
(A) Range up to 100,000 megohms, testing pressures up to 5,000 volts.
(B) Range up to 50,000 megohms, testing pressures up to 2,500 volts.
Three voltage instruments (e.g. 1,000, 2,500, 5,000 volts) also available.

C. Medium duty Series 2 testers in aluminium cases. Hand driven or mains operated.
Ranges up to 2,000 megohms, testing pressures up to 1,000 volts.
Three voltage instruments (250, 500 & 1,000 volts) also available.
A single voltage hand driven instrument can be fitted with a continuity range 0-100 ohms.

D. Light duty Series 4 testers in black plastic cases. Hand driven only.
Ranges up to 100 megohms, testing pressures up to 500 volts.
Can be fitted with continuity range 0-100 ohms.

E. Pocket size Series 3 testers (weighs 1.4 kgs.) in red plastic cases.
Hand driven variable pressure generators only. Ranges up to 100 megohms, testing pressure up to 500 volts.

Complete technical literature for all Evershed products is available on request.

EVERSHED & VIGNOLES LTD CHISWICK · LONDON W4 · *Telegrams & Cables: Megger London Telex.*

7117

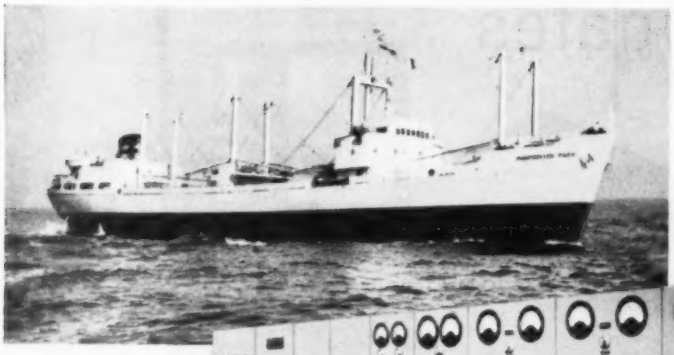
Leading the way...

'ERSKINE HEAP' *Switchgear*

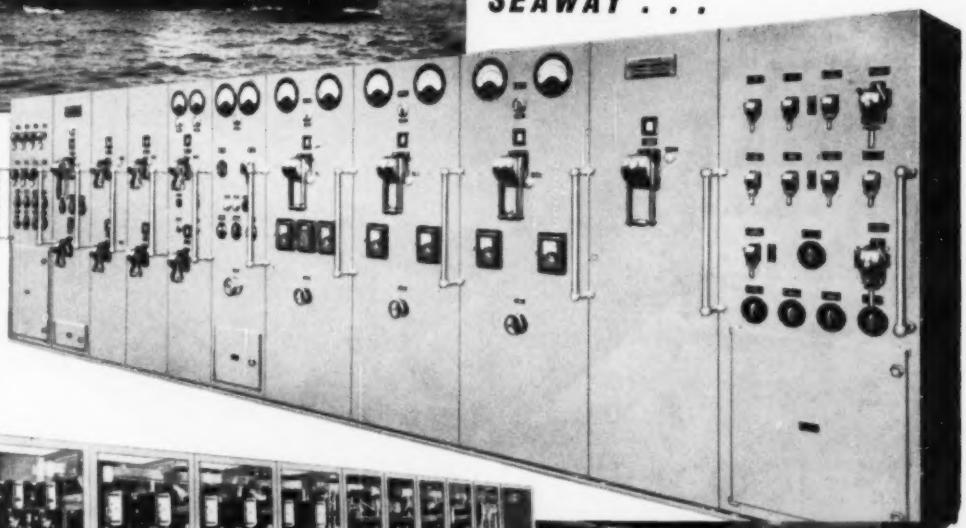
INSTALLED IN THE

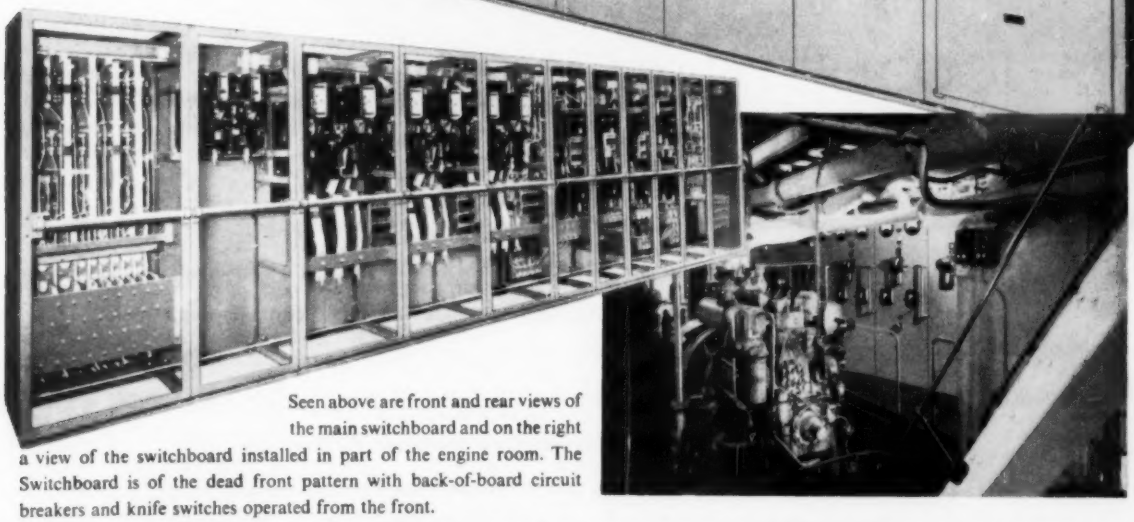
'MANCHESTER FAITH'

THE FIRST BRITISH SHIP TO ENTER THE ST. LAWRENCE SEAWAY . . .



This modern cargo ship, together with her sister ship, "Manchester Fame", both of which have Erskine Heap main switchboards, were built for Manchester Liners Ltd. by Austin & Pickersgill Ltd., Electrical Contractors, Sunderland Forge & Engineering Co. Ltd.





Seen above are front and rear views of the main switchboard and on the right a view of the switchboard installed in part of the engine room. The Switchboard is of the dead front pattern with back-of-board circuit breakers and knife switches operated from the front.

WE MANUFACTURE :- **L.T. SWITCHGEAR 50/7,000 Amperes. E.H.T. SWITCHGEAR up to 11 kV. 250 MVA rupturing capacity. MOTOR CONTROL GEAR ¼/5000 H.P.**

ERSKINE, HEAP & Co LTD

SWITCHGEAR SPECIALISTS

Head Office & Works
BROUGHTON, MANCHESTER (7)

London Office
GRAND BUILDINGS, TRAFALGAR SQ., W.C.2

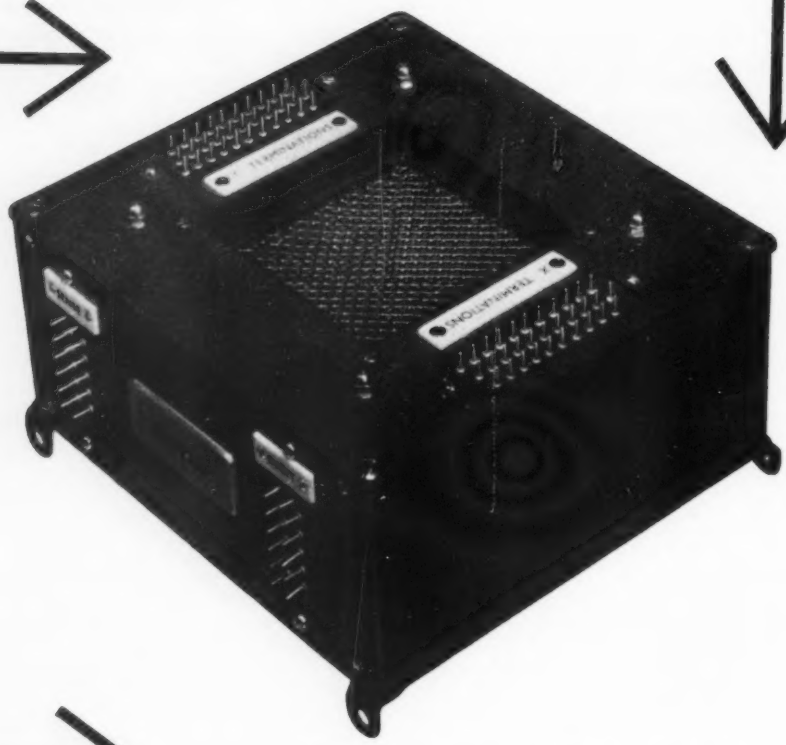
BRANCH OFFICES AND AGENCIES IN ALL PARTS OF THE WORLD

May we have your enquiries ?

735 A

Welcome to our Stand No. A.9, ELECTRICAL ENGINEERS EXHIBITION, Earls Court, London, April 5th-9th

ferrites and laminates



FORMICA* laminates – the finest quality made – are contributing to modern computer design. For example, all terminal panels and matrixes of this 1024 word ferrite core store by *The Plessey Company Limited* are produced from FORMICA GE.10 Epoxy Glass fibre laminate – a grade of exceptional mechanical and electrical properties with remarkable resistance to heat, moisture and chemicals. Another illustration of FORMICA's part in the electrical development of today.

All FORMICA laminates are tested for quality, performance and reliability.

FORMICA LTD

for electrical insulation

Paper, fabric, glass and copper clad laminates. Engraving and printed material

A SUBSIDIARY COMPANY OF THE DE LA RUE COMPANY LTD.
B.J.— DE LA RUE HOUSE, 84/86 REGENT STREET, LONDON W.1

*FORMICA is a registered trademark

A new and important advance
by Chloride Batteries Limited

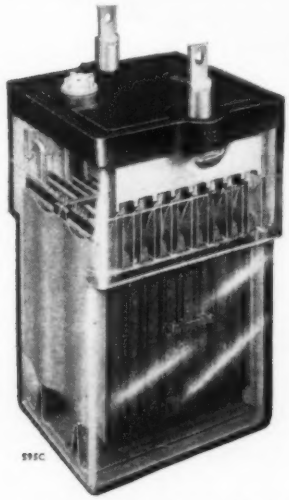
Stand-by power in

½ the space

FROM THE **NEW**

Chloride Stationary Cell

This new cell is specially designed for standby duties entailing discharge rates between, say, the 3-hour and the very high rates demanded for switch-closing purposes. With its Planté positive and pasted negative plates, Porvic microporous separators and many other improvements in material and in design, this light, robust cell will perform its duties with greater efficiency, with complete reliability and with a saving in battery space of approximately 50%. It is ideal for trickle-charge operation* and has all the remarkable length of life of the Planté type of construction. In Great Britain today standby batteries occupy millions of cubic feet of valuable space. The new Chloride cell could free almost half of it.



* *The new cell will from now onwards be fitted in all Keepalite units—the Chloride Company's automatic emergency lighting system.*

By the makers of Exide Batteries

A PRODUCT OF CHLORIDE BATTERIES LIMITED
BACKED BY WORLD-WIDE SERVICE
Enquiries to: London, Elgar 7991; Bristol 64086; West Bromwich 2361; Leeds 20248; Glasgow, Bridgeton 3734; Manchester, Blackfriars 1158; Belfast 27953

HEENAN

CLOSED CIRCUIT

AIR COOLERS

for ventilation of turbo-alternators
Lengthy experience in practical design
Wide variety of ducting and damper layouts
Highly efficient cooling surfaces
Heavy and robust construction
Special attention to ease of access and maintenance

FORCED DRAUGHT

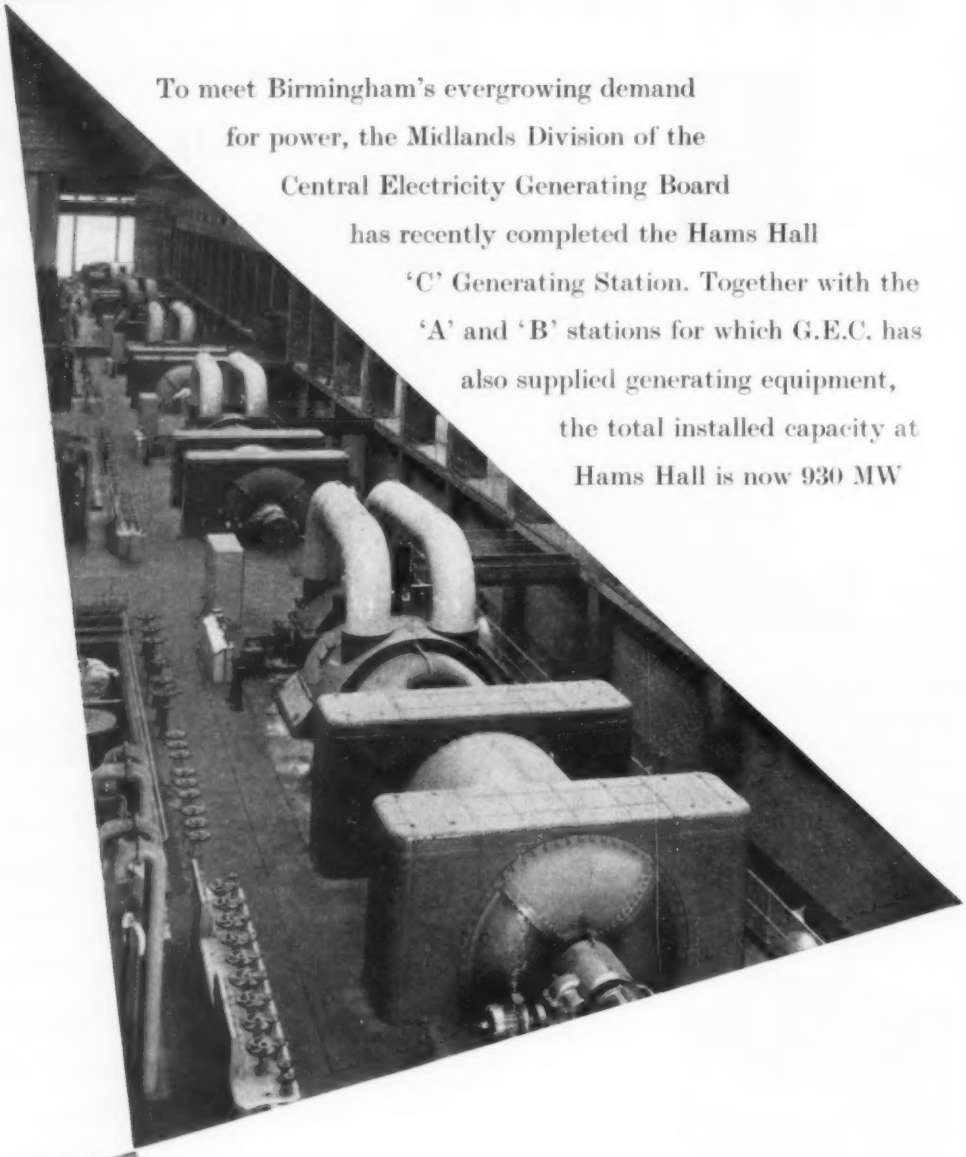
WATER COOLERS

for cooling circulating water of Diesel, Gas and Petrol Engines, Refrigerating Condensers, Air Compressors, Liquid Controllers, Process Works, etc.
Save 95% of water otherwise wasted
Robust and compact all-metal construction
Install in- or out-of-doors

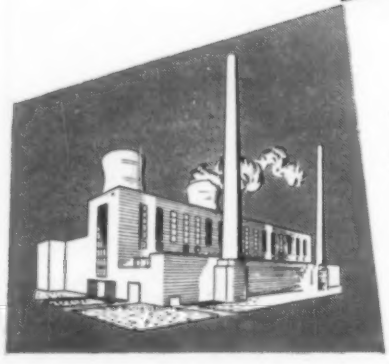
H&F

HEENAN & FROUDE LTD
WORCESTER : ENGLAND

G.E.C. for Birmingham's Power



To meet Birmingham's evergrowing demand for power, the Midlands Division of the Central Electricity Generating Board has recently completed the Hams Hall 'C' Generating Station. Together with the 'A' and 'B' stations for which G.E.C. has also supplied generating equipment, the total installed capacity at Hams Hall is now 930 MW



The General Electric Co Ltd of England,
Power Plant Division, Erith, Kent.

323

G.E.C.

A.S.T.A.Certified **fuse links** H.R.C.

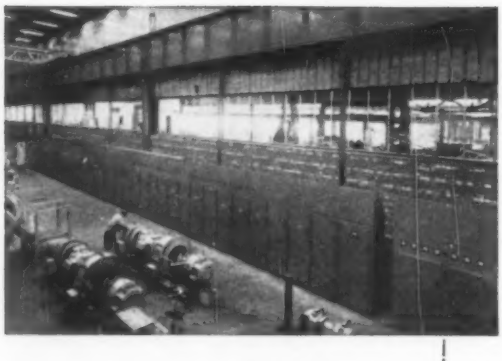
Stocked at all G.E.C. branches

Send for Publication X3730, a handy pocket-size guide to the selection of Industrial Cartridge Fuses

THE GENERAL ELECTRIC CO. LTD., MAGNET HOUSE, KINGSWAY, LONDON, W.C.2

. . . and leave the rest to GWB Control Gear

The accumulated knowledge and experience gained through the direct application of control gear in their own installations over a considerable number of years has placed G.W.B. in the unique position of having an intimate knowledge of the failings and drawbacks of conventional equipment. The introduction of G.W.B. Control Gear of the air-break type has made it particularly suitable for long life and the heavy duty conditions found in all branches of modern industry.



Steelworks duties demand the very best in electric control gear to ensure continuous production under conditions which are frequently unfavourable. G.W.B. steel mill auxiliaries control panel over 100 ft. long supplied to Samuel Fox & Company Ltd., Sheffield.

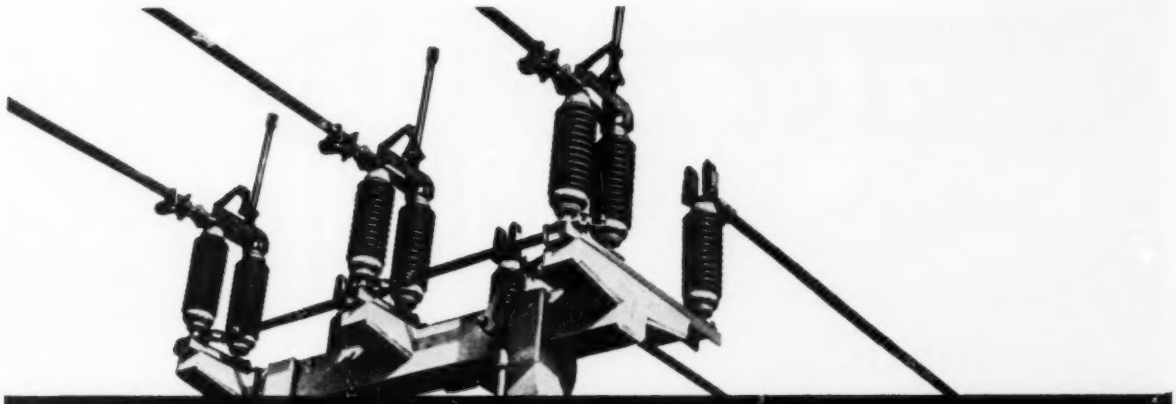
GWB

G.W.B. FURNACES LIMITED (CONTROL GEAR DIVISION)

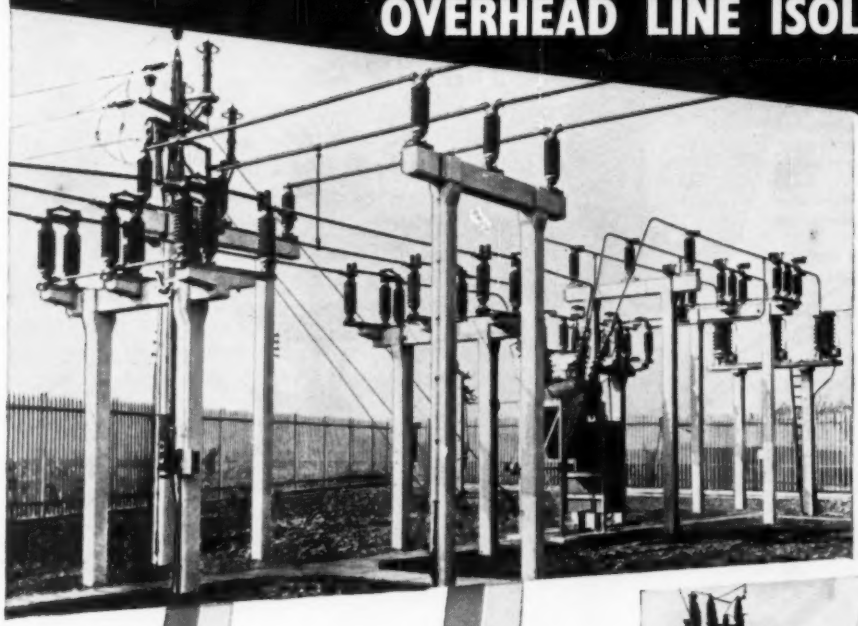
P.O. BOX 4 · DIBDALE WORKS · DUDLEY · WORCS. *Telephone: Dudley 4284 & 5081*

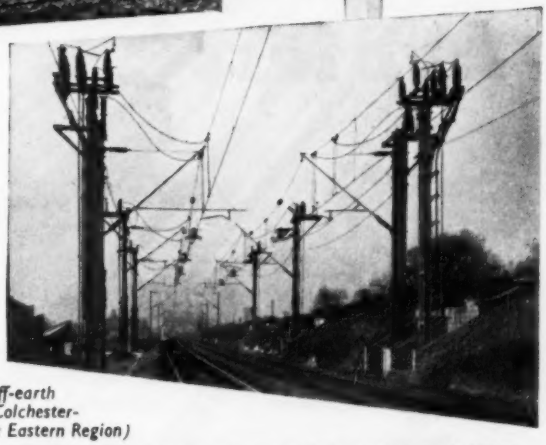
ASSOCIATED WITH GIBBONS BROS. LTD. AND WILD-BARFIFLD ELECTRIC FURNACES LTD.

G.W.B. 412



HACKBRIDGE AND HEWITTIC H.V. OUTDOOR OVERHEAD LINE ISOLATORS





Illustrated above:
Close up and general views of Hackbridge and Hewittic type RVB and RDB 33 kV isolators installed at Shepreth Substation, Eastern Electricity Board.

Illustrated right:
Hackbridge and Hewittic 25 kV on-off-earth rotating type isolators installed on the Colchester-Clacton-Walton Lines (British Railways Eastern Region)

HACKBRIDGE AND HEWITTIC ELECTRIC COMPANY LTD

HERSHAM · WALTON-ON-THAMES · SURREY

Telephone: Walton-on-Thames 28833 (8 lines) *Telegrams & Cables: "Electric, Walton-on-Thames"*

TRANSFORMERS · RECTIFIERS · LINE GEAR

Heatrae of Norwich

present

The most up-to-date

AUTOMATIC ELECTRIC WATER HEATER

Only 10 inches (25·4 centimetres) wide, yet delivering up to 9 gallons (40·9 litres) of hot water per hour, the Heatrae "Express" is ideal for economy use.
The highest standards of British workmanship are evident throughout and never before has such value, performance, style and craftsmanship been embodied in an automatic electric water heater.
An economy electric 'Eye' glows when the current is on and is extinguished when the correct temperature is reached.
The special dispenser outlet ensures smooth even flow and instant cut-off when the valve is closed.
Available in loadings of 3kW or 2kW at 230/250 volts, or 200/220 volts, A.C. only.
Finished cream or white.
U.K. Price: £10. 12. 6. Plus P. Tax: £2. 1. 5.
Full details on leaflet No. 92 sent on request.

Heatrae Lido 'Express'

EXCLUSIVE ECONOMY EYE

SPECIAL DISPENSER OUTLET CONTROL

★

9

GALLONS of PIPING HOT WATER per hour—every hour !

Manufacturers of Electric Water Heaters, Oil Heaters, Immersion Heaters, Urns, Towel Rails, Airing Cupboard Heaters, Electric Fires, Flameproof Heating Apparatus, Food Trolleys, Warming Plates, Air Heaters. Specialists in Steam Heated Oil Heaters and Calorifiers for Shipboard.

HEATRAE LIMITED

Pioneers since 1920 in all-electric water heaters

Postal code: NORFOLK NOR 29A - ENGLAND

Telegrams: HEATRAE · NORWICH Telephone: NORWICH 25131 (Private Exchange)

REACH FOR INVICTA

for SUCCESS

Successful arc welding is assured with INVICTA Electrodes. They are specifically designed for each particular job, and INVICTA cover a wide range of arc welding requirements. For simplicity of operation, welding in all positions, easy slag removal, freedom from impurities, smooth deposit, first-class mechanical properties, and economical welding.

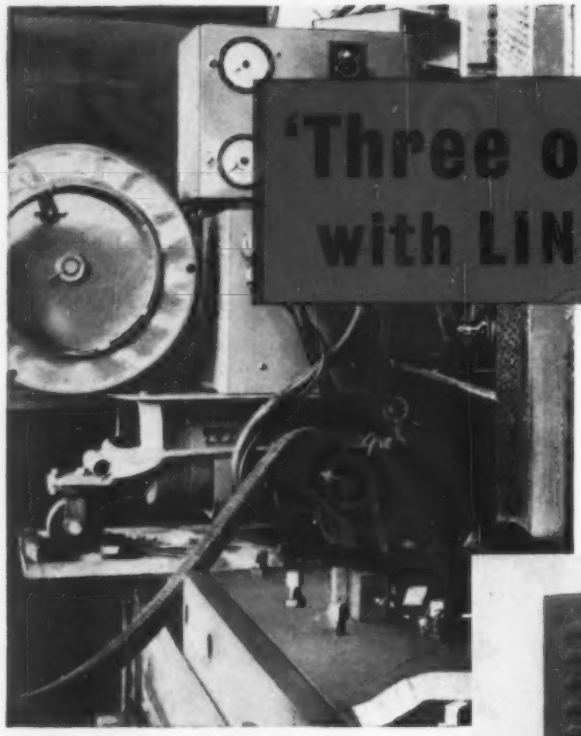
Used by some of the largest Shipbuilding and Engineering Works throughout the World

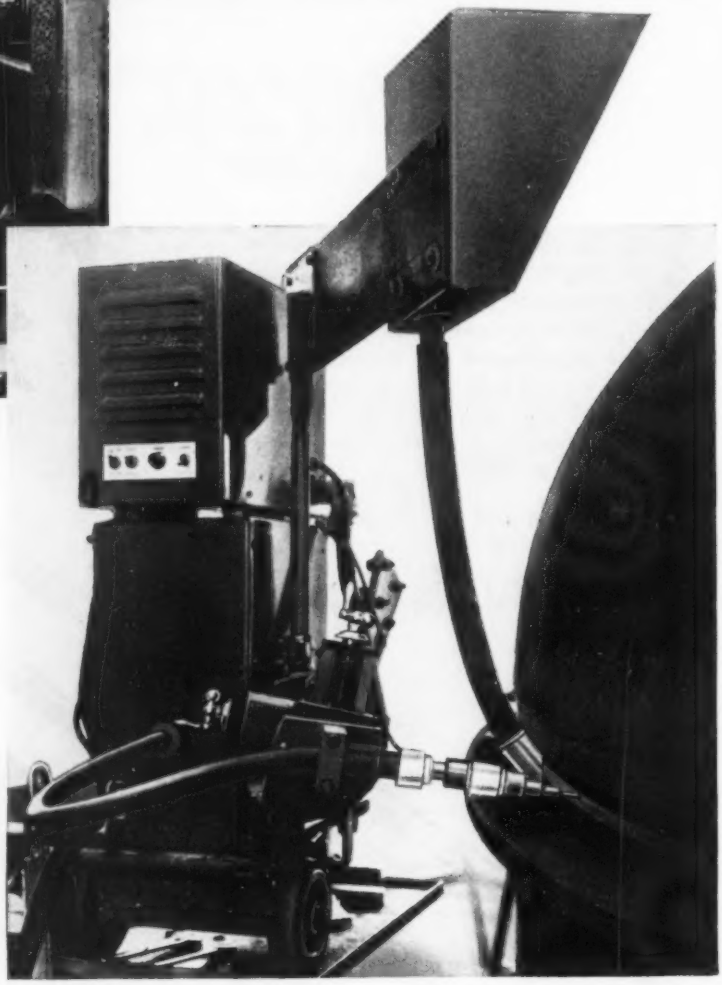
★*Write NOW for full details of the complete range of INVICTA Electrodes which cover every industrial purpose.*

(Member of the Owen Organisation)

INVICTA ELECTRODES LTD., BILSTON LANE, WILLENHALL, STAFFS. Tel: James Bridge 3131 Ext. 308

'Three o'clock' welding with LINCOLNWELD





THE LINCOLNWELD Universal Tractor in action at the Derby works of International Combustion Co. Ltd. The illustrations show the Universal Tractor automatically welding in the '3 o'clock' position, a section of one of 4 heat exchangers for The Advanced Gas Cooled Reactor, being built at Windscale, Cumberland, for the United Kingdom Atomic Energy Authority. (Photographs by the courtesy of International Combustion Co. Ltd. and U.K.A.E.A.

Butt welding, Fillet welding, Lap welding and now horizontal/vertical '3 o'clock' welding—all are possible with the latest LINCOLNWELD UNIVERSAL TRACTOR Submerged Arc Welding Unit.

Don't spend money-make money with LINCOLNWELD! For further details of how Lincolnweld extra versatility can help you solve your welding problems, please write to:

The Automatic Division

GKN **LINCOLN ELECTRIC COMPANY LIMITED**

WELWYN GARDEN CITY · HERTS · ENGLAND · Telephone: WELWYN GARDEN 920/4 · 4581/5

MK 168E DHB

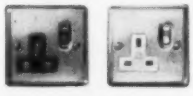
Whether it's a socket-outlet

switchsocket-outlet

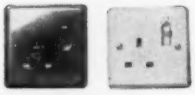
pilot-lamp switchsocket-outlet

rated at 2, 5, 13 or 15 amperes

with brass plate finished BMA or matt chrome



or moulded in brown or ivory

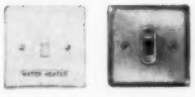


whether it's a fused spur-box

with a switch

or a pilot-lamp

a water-heater switch



a one or two gang Plateswitch

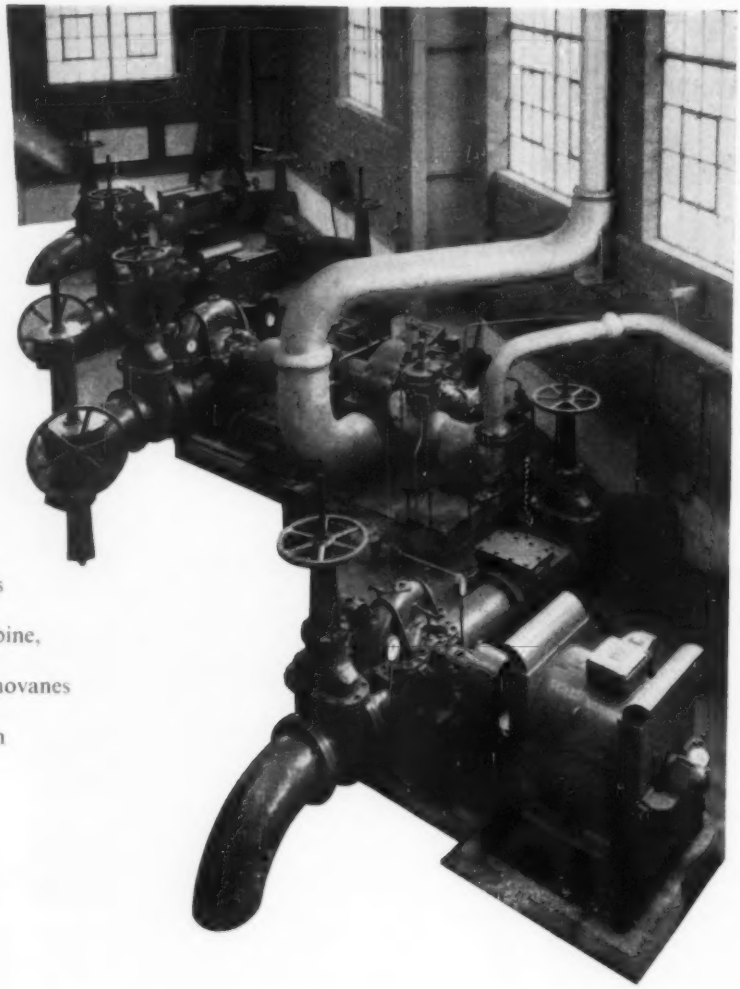
or even a clock connector

MK make a design to fit the

standard box with $2\frac{3}{8}$" centres

.....(and all the many 1 and 2 gang MK Gridswitch combinations also have $2\frac{3}{8}$" centres)

M. K. ELECTRIC LIMITED
EDMONTON, LONDON, ENGLAND



Mather & Platt pumps and motors on furnace cooling duty in the pump house of a large steel works. In the foreground is a 12″/15″ Medivane delivering 4,500 g.p.m. against a 140 ft. head, and driven at 1,470 r.p.m. by a drip-proof squirrel-cage induction motor rated at 260 b.h.p., 2,750 volts. Next to this is a 16″/20″ Medivane driven by steam turbine, and in the background are two 17″/20″ Lonovanes driven by drip-proof squirrel-cage induction motors.

PUMPS and MOTORS

for all

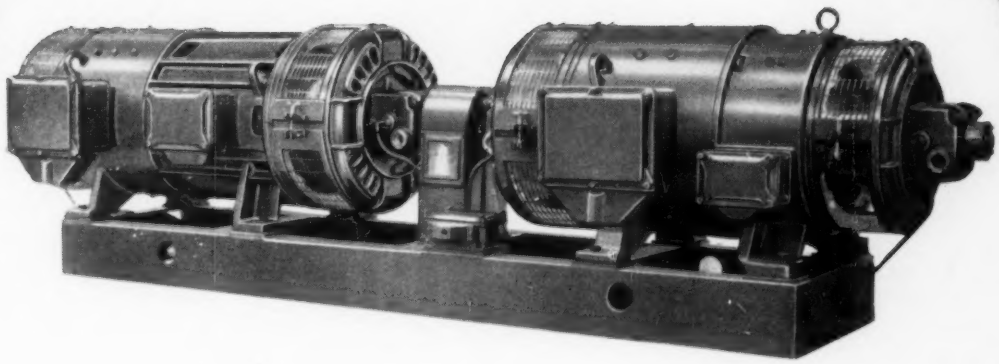
Duties and all Services

Mather & Platt
LIMITED

PARK WORKS, MANCHESTER, 10

Telephone: COLlyhurst 2321
Telegrams: Mather, Manchester

A.25



MAINS/BATTERY CONTINUITY SET

FOR MAINTAINING ESSENTIAL SUPPLIES IN THE EVENT OF MAINS FAILURE

Mawdsley's

ROTATING ELECTRICAL EQUIPMENT ½kW—300kW

MAWDSLEY'S LTD. DURSLEY GLOUCESTERSHIRE

Specialists in Specials

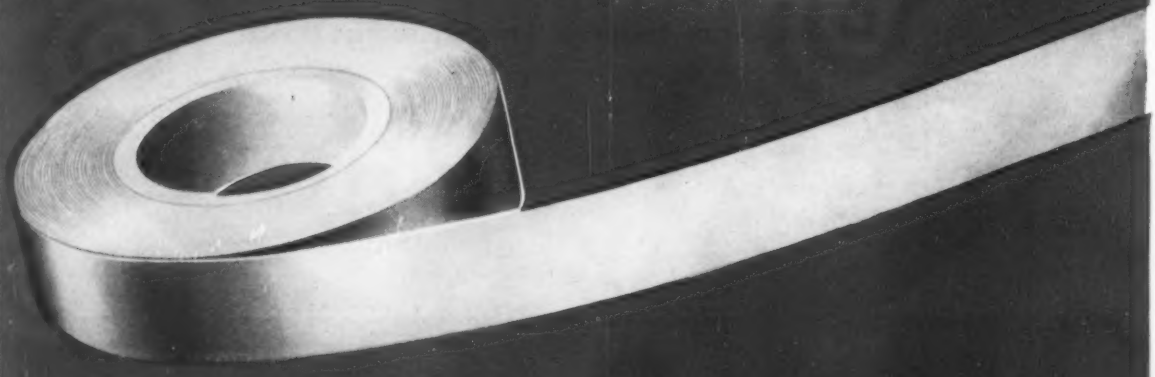
TELEPHONE: DURSLEY : 2386 : 5 LINES : GRAMS: ZONE, DURSLEY
London Office: 28 Queen Anne's Gate, Westminster, S.W.1 : Telephone: Whitehall 8892

Wide Tapes · Narrow Tapes

Thick Tapes · Thin Tapes

Micanite & Samicanite* TAPES With various reinforcing materials and bonding agents.

Empire Varnished TAPES In various combinations of base material and varnish.



M&I make all sorts of Electrical Insulating Tapes

m and i the electrical insulation people

THE MICANITE & INSULATORS CO., LTD.,

Empire Works, Blackhorse Lane, Walthamstow, London, E.17

TELEPHONE: LARKWOOD 2020 TELEGRAMS: MYTITE, LONDON TELEX 25163: 25163

*MICANITE is the name for electrical insulating materials manufactured from "SAMICA" mica paper and available in Great Britain, Northern Ireland, Eire and most of the world. Company-made through the agencies of Associated Electrical Industries Ltd., the sole licensee for these territories. ® "SAMICA" is a registered trade mark.

Size 'N' for 3,500,000 G.P.H.

Rotary Water Strainers

The Hick Hargreaves self-cleaning enclosed Rotary Water Strainer is proving, in service throughout the world, to be the most effective means of removing floating debris. The strainer comprises a motor-driven wheel, slowly rotating inside a casing, the straining medium which is between the spokes being so designed to prevent the interlacing of fibrous matter. The head loss through the strainer does not exceed 2 feet. The debris is removed from the strainer by a series of jets, and discharged from an internal chamber which is effectively sealed off from the main water space. All water connections are placed in the lower half of the casing and large access doors are provided for routine examination. Installation is extremely simple, no extensive foundation work being necessary. The strainer can be located on either the suction or discharge side of the circulating water pumps.

The Hick Hargreaves Rotary Strainer is available in a range of capacities up to 5,000,000 g.h.p. with mesh of $\frac{1}{16}$" to $\frac{1}{4}$" diameter inscribed circle.

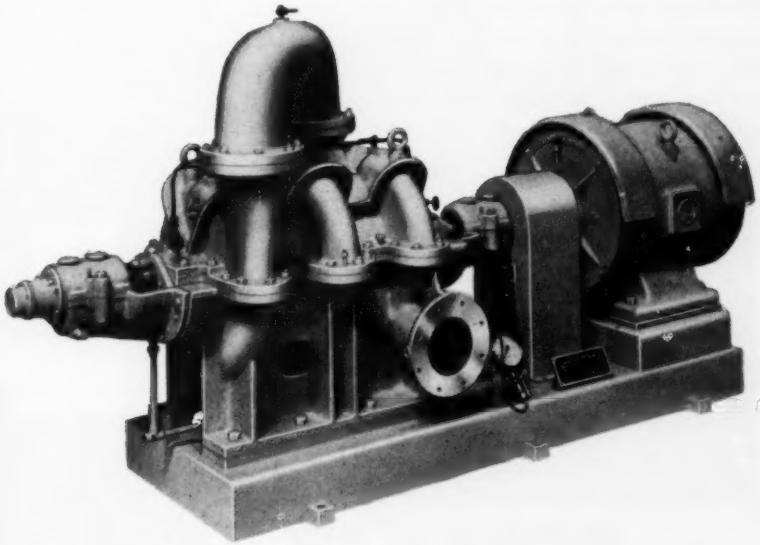
Hick Hargreaves AND COMPANY LTD · BOLTON

H. 139E

Mirrlees'

CONDENSATE PUMPS

Three-Stage Condensate Extraction Pump for Mirrlees Surface Condensing Plants.



THE MIRRLEES WATSON CO LTD

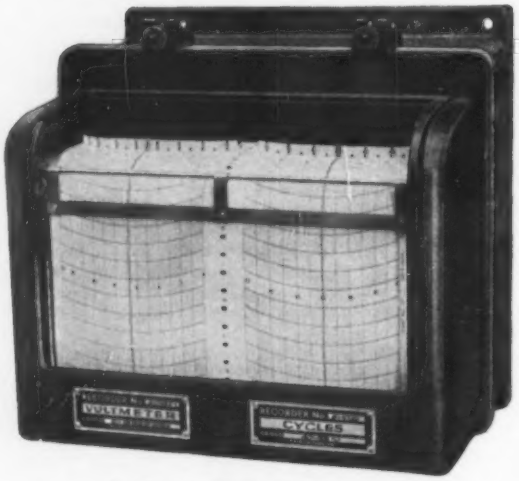
Scotland Street, Glasgow, C5

London Office: 38 Grosvenor Gardens, SW1

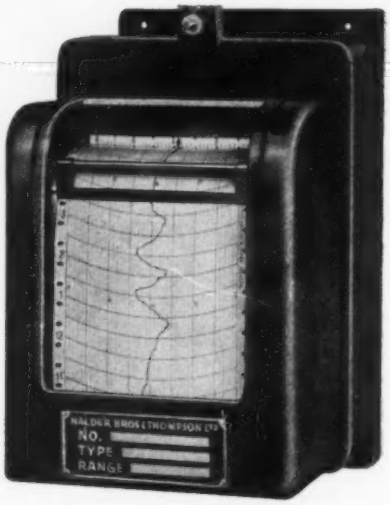
A Complete Range of Graphic Recorders

Single, Double or Triple instruments
all in Flush, Projecting or Portable mountings

AMMETERS
VOLTMETERS
WATTMETERS
FREQUENCY METERS
POWER FACTOR METERS



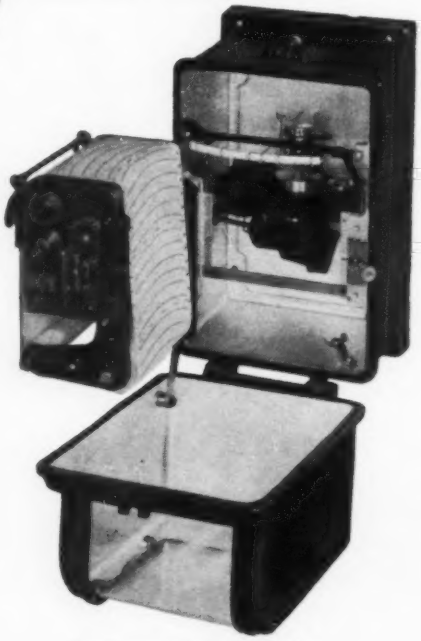
Double instrument (Projecting)



Single instrument (Projecting)

Our improved driving mechanism gives very accurate timing using hand wound or synchronous motor clocks.

Standard Chart Speed—1 inch per hour (a 65 foot roll lasts for a whole month). Multi-speed charts can also be supplied.



Easy access for recharting

Check List of Nalders Products

Ammeters Voltmeters	Power Factor meters Electrostatic voltmeters
Wattmeters Vectormeters	Phase Sequence indicators Contact-making instruments
Synchroscopes Frequency meters Graphic Recorders	Numerous Protective Relays Miniature Circuit-Breakers Earth Proving Supply Switches
Controller Mountings Hoseproof Flameproof or Standard **Also** Portable Instruments	**Switchboard Mountings** (Flush and Projecting) Square or Round in Pressed Steel or Aluminium **Also** Sector Edgewise and Hermetically Sealed

For Technical Pamphlets, *of any of our products, please telephone or write*

Nalder Bros & Thompson Ltd

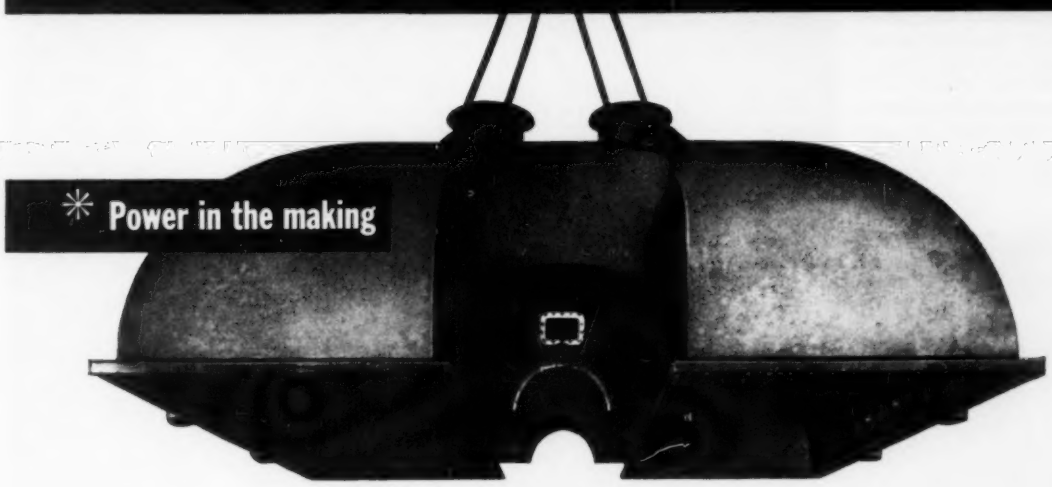
ELECTRICAL INSTRUMENTS

ESTABLISHED IN LONDON IN 1884

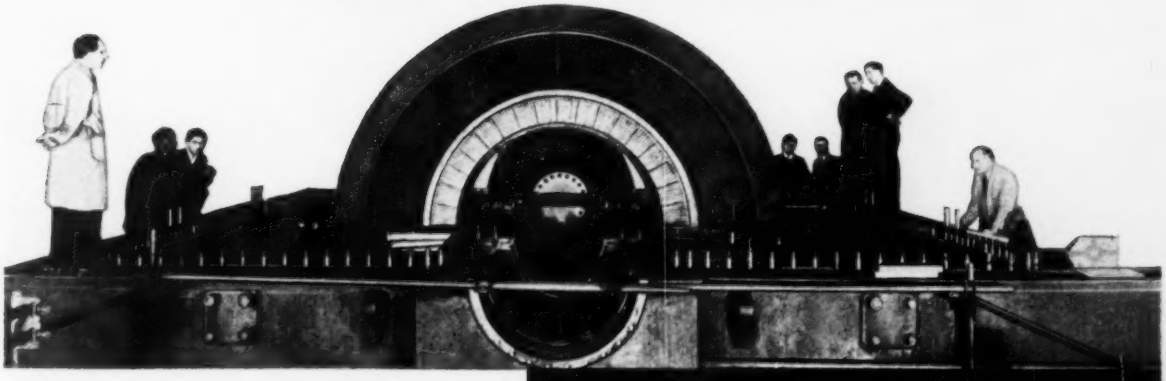
Dalston Lane Works London E.8

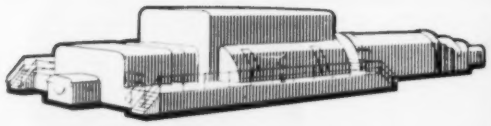
'*Phone* **CLIssold 2365** '*Grams* Occlude Hack London

Constructing STEAM TURBO-GENERATORS



✳ Power in the making





✳ When Sir Charles Parsons produced the first steam turbo-generator he said that the larger the plant the more economical it would be. This is realised today with the tremendous electrical output of the very large turbo-generators under construction at PARSONS Heaton Works. Some idea of the size of the large and powerful steam turbine driving units can be seen from this view of the cover for a low pressure cylinder on a PARSONS 200 MW turbo-generator. The cover is being lowered for a trial fit prior to inclusion of the bladed shaft.

TURBO-GENERATORS · POWER TRANSFORMERS · CONDENSING PLANT

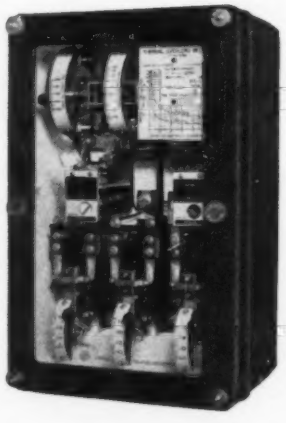
PARSONS

C. A. PARSONS & CO. LTD.
HEATON WORKS · NEWCASTLE UPON TYNE 6

F E R B A N E
is the largest Power Station outside the U.S.S.R. using milled peat. In this and other thermal Power Stations of the Electricity Supply Board of Ireland, P & B Golds Relays provide motor protection. This photograph shows the peat bog in the background.

BORD SOLATHAIR AN LEICTREACHAIS
choose P&B Golds Relays

P & B Relays give full protection for motors with any starting periods or currents under extremes of ambient temperature.
P & B Golds Relays protect against phase failure, overload, short circuit or earth fault.
P & B Stalling Relays give complete protection against stalling under all conditions. Send for current literature.



P&B
PROTECTION RELAYS

THE P & B ENGINEERING CO. LTD
CROMPTON WAY
CRAWLEY · SUSSEX
Telephone Crawley 1004

Inspector's Corner

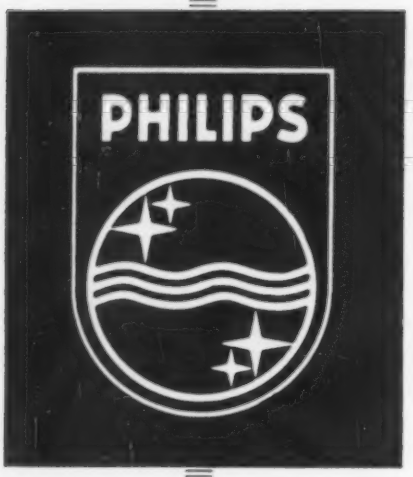
Suspicious types, Inspectors. Never take things for granted. Always measuring and checking limits. Miserable lot! Necessary evil though, come to think of it. Components for heavy electrical gear *must* be accurate. Or there's trouble on erection. Big parts are impressive of course. Make a good picture. But Permali Inspectors check tens of thousands of parts every week. Some big. Some small. But *all* important to somebody. Not such a bad lot really, Inspectors!

Inspection of 10 ft long tension rod for 275kV oil circuit breaker. Hole centre at one end must be parallel to the plane of the rod at the other end to within .006 in.

PERMALI Insulation

Totally tested . . .
. . . most reliable

PERMALI LIMITED GLOUCESTER ENGLAND TELEPHONE: 24941

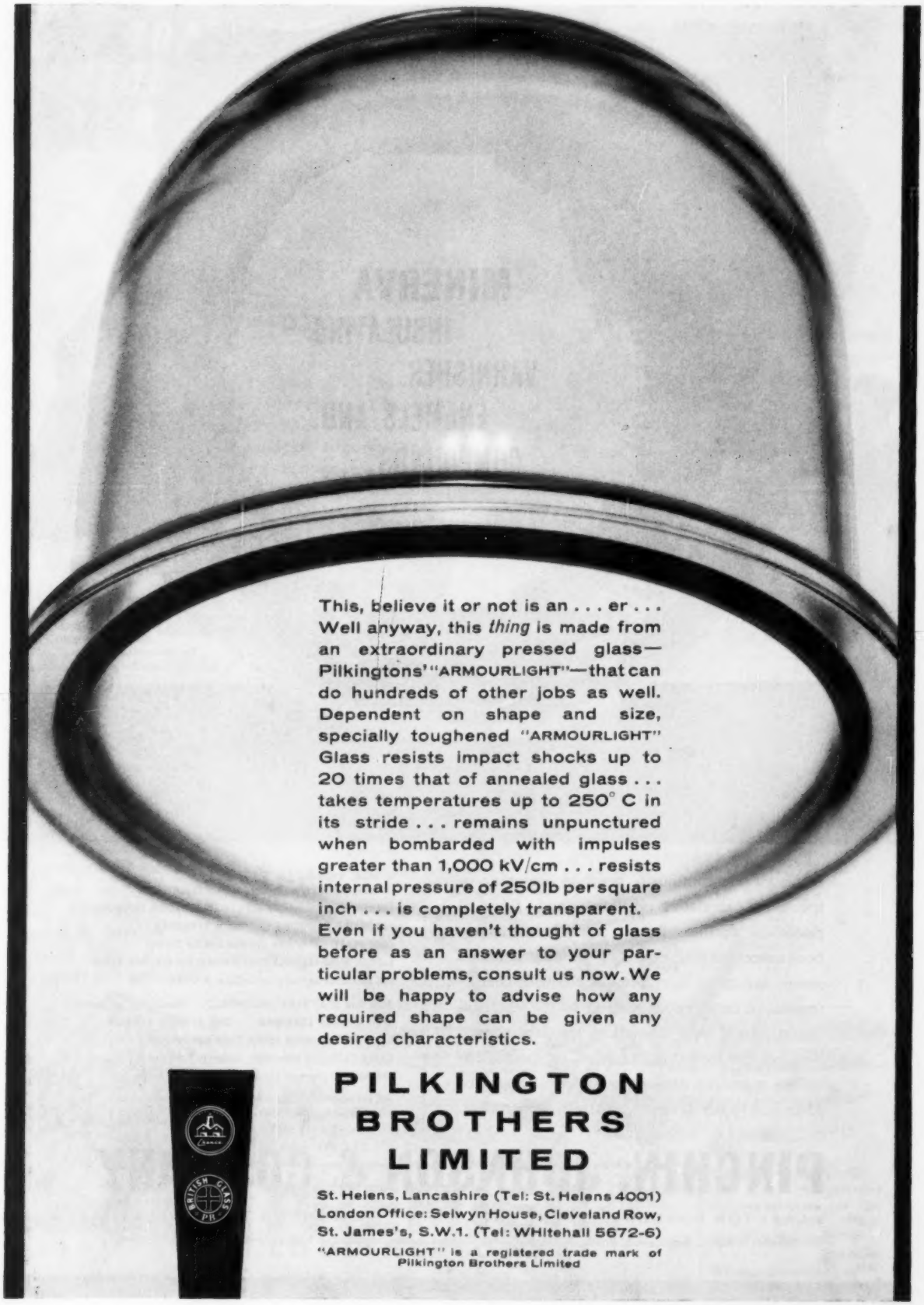


This emblem guides the choice of millions

Radio & Television Receivers.
Radiograms & Record Players.
Gramophone Records.
Tungsten, Fluorescent, Blended and
Discharge Lamps & Lighting Equipment.
'Philishave' Electric Dry Shavers.
'Photoflux' Flash Bulbs.
High-Frequency Heating Generators.
X-ray Equipment for all purposes.
Electro-Medical Apparatus.
Electrically-heated Blankets.
Heat Therapy Apparatus.
Arc & Resistance Welding
Plant and Electrodes.
Electronic Measuring Instruments.
Magnetic Filters.
Battery Chargers and Rectifiers.
Sound Amplifying Installations.
Cinema Projectors.
Tape Recorders.
Hi-Fi Equipment.
Health Lamps.
Hearing Aids.

PHILIPS ELECTRICAL LTD · CENTURY HOUSE · SHAFTESBURY AVE · LONDON W.C.2

(P1030)



This, believe it or not is an . . . er . . . Well anyway, this *thing* is made from an extraordinary pressed glass—Pilkingtons' "ARMOURLIGHT"—that can do hundreds of other jobs as well. Dependent on shape and size, specially toughened "ARMOURLIGHT" Glass resists impact shocks up to 20 times that of annealed glass . . . takes temperatures up to 250° C in its stride . . . remains unpunctured when bombarded with impulses greater than 1,000 kV/cm . . . resists internal pressure of 250 lb per square inch . . . is completely transparent.
Even if you haven't thought of glass before as an answer to your particular problems, consult us now. We will be happy to advise how any required shape can be given any desired characteristics.

PILKINGTON BROTHERS LIMITED

St. Helens, Lancashire (Tel: St. Helens 4001)
London Office: Selwyn House, Cleveland Row, St. James's, S.W.1. (Tel: WHitehall 5672-6)

"ARMOURLIGHT" is a registered trade mark of Pilkington Brothers Limited

Magnet frame for 4,000 h.p. Mill Motor treated with P.J. Black Sealing and Finishing Varnish
By kind permission of
General Electric Co. Ltd., Birmingham

Additions are continually made to our range of specialised insulating varnishes and electrical machinery finishes. Recent research has largely been concerned with exploiting the latest synthetic resins, and many new formulations with characteristics of considerable interest to the electrical industry have been evolved in our laboratories. Requests for further information, or specific enquiries regarding insulating problems, should be addressed to our Insulating Varnish Department.

STOVING VARNISHES
(Natural Resin Type) (Synthetic Resin Type)
THERMO-SETTING VARNISHES · SOLVENTLESS VARNISHES
AIR-DRYING VARNISHES · CLOTH VARNISHES
CORE-PLATE VARNISHES (Stoving and Air Drying)
COPPER WIRE ENAMELS (Oleo-resinous and Synthetic Types)
All the above are supplied in black and clear.

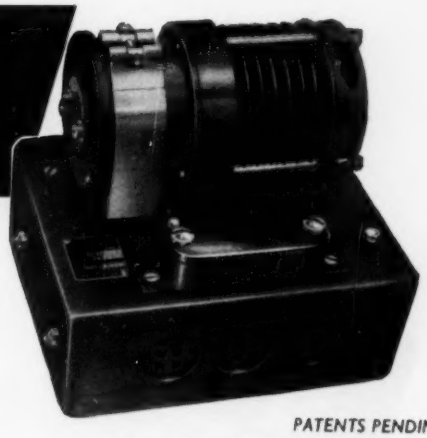
ACID AND HEAT RESISTING ENAMELS. *Available in all colours.*
MICA BONDING VARNISHES · COIL STICKING VARNISHES
SLEEVING VARNISHES (Black, Clear and Colours)
CABLE LACQUERS (Non-flam., Cellulose Type and P.V.C.)
COMPOUNDS (Various Types)
All the materials listed conform to B.S. Specifications wherever applicable.

PINCHIN, JOHNSON & COMPANY

4 CARLTON GARDENS · LONDON · S.W.1 · TELEPHONE TRAFALGAR 5600

Branches: Belfast, Birmingham, Bootle, Brighton, Bristol, Glasgow, Leeds, Manchester, Newcastle-on-Tyne & Southampton

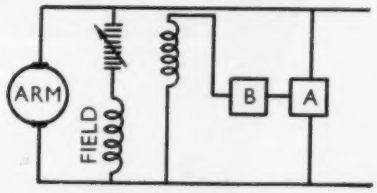
TRANSISTORISED AUTOMATIC VOLTAGE REGULATORS



Model shown is for the control of a 28 Volt D.C. generator for use on aircraft.

Regulation closer than ± 1% between extremes of temperature from −60°C to +70°C
Speed of response 50/60 milliseconds.
For industrial purposes at normal ambient temperatures regulation within ± 0·5%.
Dimensions 5" × 6" × 5½" high.
Weight 4 lbs.

PATENTS PENDING



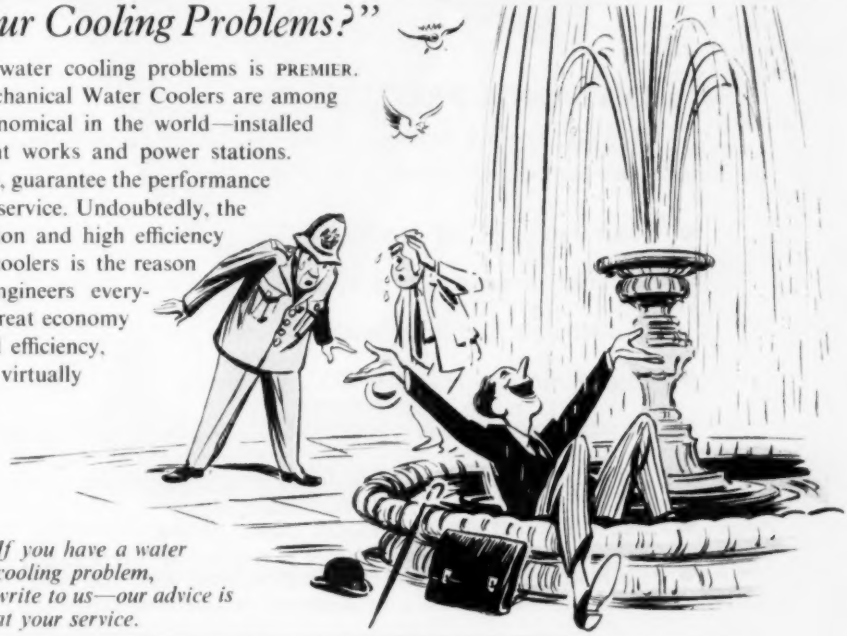
A=REFERENCE BRIDGE
B=TRANSISTOR AMPLIFIER

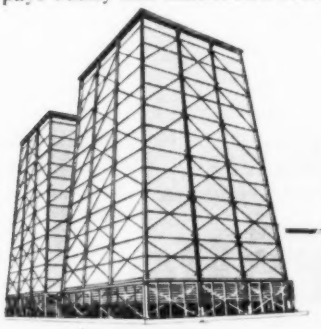
NEWTON DERBY

NEWTON BROS (DERBY) LTD
ALFRETON ROAD · DERBY
Phone: Derby 47676 (4 lines) *GRAMS: DYNAMO · DERBY*
London Office: IMPERIAL BUILDINGS, 56 KINGSWAY, W.C.2

"Have you solved your Cooling Problems?"

Undoubtedly, the answer to all water cooling problems is PREMIER. PREMIER Cooling Towers and Mechanical Water Coolers are among the most highly efficient and economical in the world—installed in many of the world's important works and power stations. PREMIER design and erect the plants, guarantee the performance and give a 100 per cent after-sales service. Undoubtedly, the scientifically engineered construction and high efficiency and economy of PREMIER water coolers is the reason why they are acclaimed by engineers everywhere. IT IS A FACT that the great economy achieved by PREMIER in increased efficiency, saving of water rates and space virtually pays outlay and installation costs.





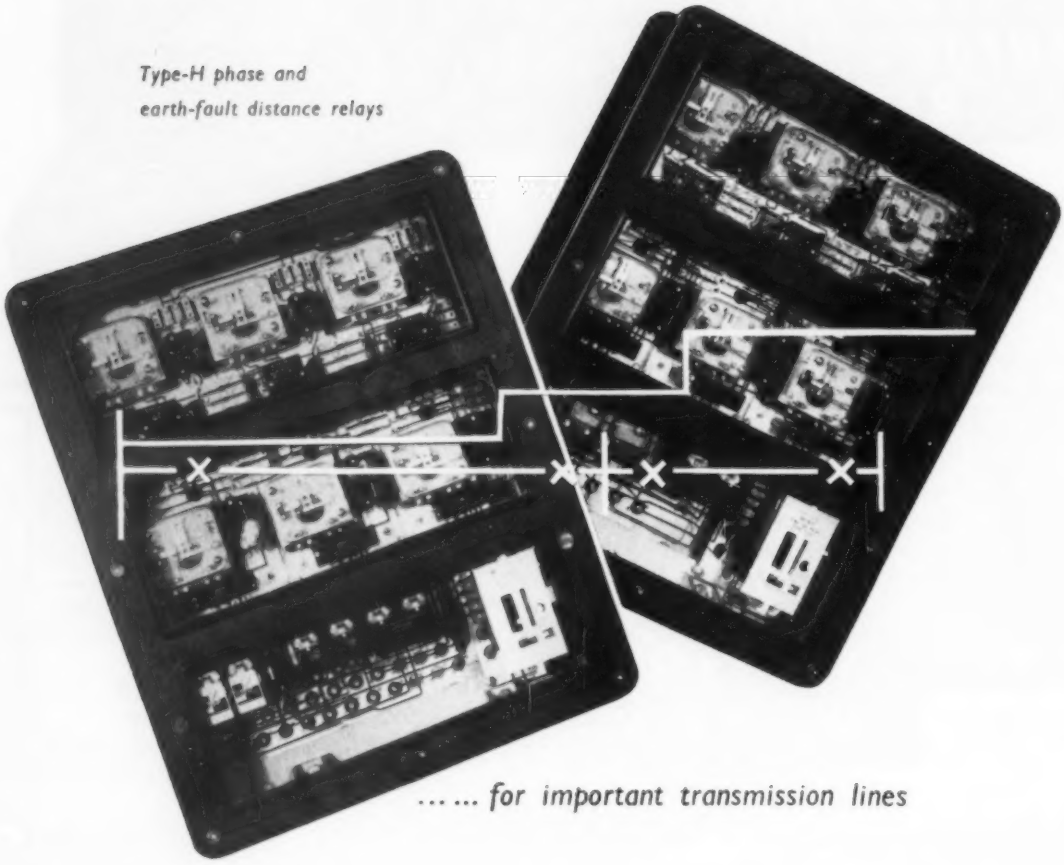
If you have a water cooling problem, write to us—our advice is at your service.

PREMIER
COOLING TOWERS

The PREMIER COOLER AND ENGINEERING CO. LTD., Shalford, Nr. Guildford, Surrey

WE *do the designing ourselves*
WE *manufacture our own plants*
WE *erect the plants ourselves*
WE *guarantee the performance*

Type-H phase and
earth-fault distance relays



..... for important transmission lines

DISTANCE-PROTECTION

Reyrolle type-H high-performance distance protection incorporates the following important features:

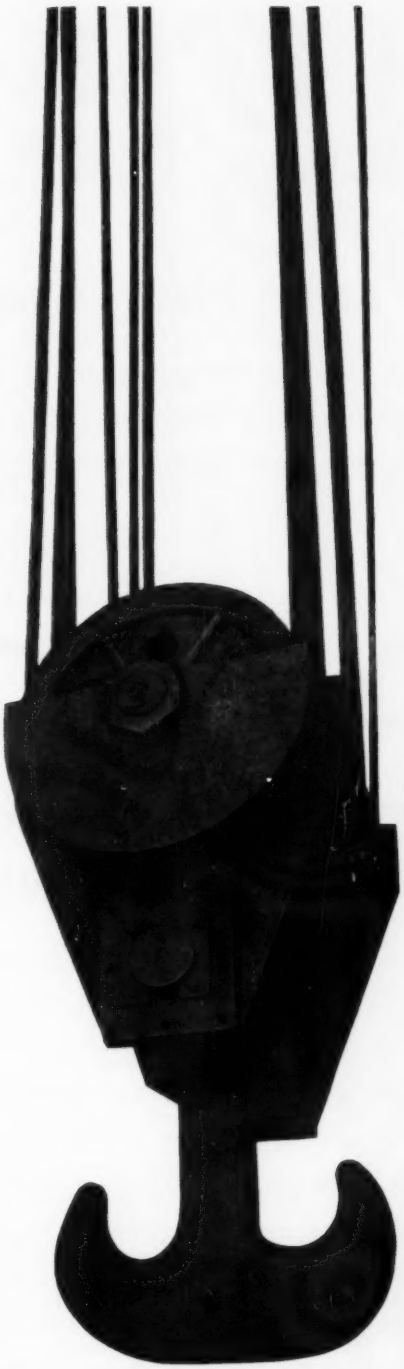
- High speed for all types of fault
- Accurate measurement for exceptionally wide range of source to line impedance
- Negligible over-reach on D.C. transients
- Separate moving-coil elements for earth-faults and phase-faults
- All relay-elements identical and easily removable
- Self-contained design reduces panel wiring
- Built-in phase-selectors for single-phase auto-reclosing if required

Ask for Pamphlet 1297

Reyrolle

A. REYROLLE & COMPANY LIMITED - HEBBURN - COUNTY DURHAM - ENGLAND

TO LIFT THE LARGEST ALTERNATORS YET ENVISAGED



The hook of the 175 ton 'traveller' in our new turbine shop at Hartlepool. Here we can build, to Brown Boveri design, the largest turbo-alternators yet envisaged. At Hartlepool we, of course, also build small turbines, and many other things besides: industrial turbo-alternators down to 500 kW, gas turbines, axial and centrifugal blowers and exhausters, water-tube boilers of Foster-Wheeler design, Economic type boilers, feed heaters, condensers, rotary cooling-water strainers, etc . . . in fact all the major equipment of a power station.

R W G

RICHARDSONS WESTGARTH (HARTLEPOOL) LTD.

A member of **THE RICHARDSONS WESTGARTH GROUP** which co-ordinates the land and marine activities of:

THE NORTH EASTERN MARINE ENGINEERING CO. LTD.
PARSONS MARINE TURBINE CO. LTD.
GEORGE CLARK & NORTH EASTERN MARINE (SUNDERLAND) LTD.
RICHARDSONS WESTGARTH (HARTLEPOOL) LTD.
THE HUMBER GRAVING DOCK & ENGINEERING CO. LTD.
RICHARDSONS WESTGARTH ATOMIC LTD.

ASSOCIATED COMPANY: ATOMIC POWER CONSTRUCTIONS LTD.

RICHARDSONS WESTGARTH (Hartlepool) LTD., HARTLEPOOL, CO. DURHAM
and at 58 Victoria Street, London, S.W.1. 59 Mosley Street, Manchester, 2. 75 Buchanan Street, Glasgow, C.1

sangamo

METERS AND TIME SWITCHES

SINGLE PHASE AND POLYPHASE WATTHOUR METERS

SYNCHRONOUS TIME SWITCHES

SYNCHRONOUS MOTORS AND MOTOR UNITS

*

weston

ELECTRICAL MEASURING INSTRUMENTS

PANEL & SWITCHBOARD INSTRUMENTS

D.C. Moving Coil, A.C. Rectifier, H.F. Thermocouple, A.C./D.C. Moving Iron

PORTABLE INSTRUMENTS

D.C. Moving Coil, A.C. Rectifier, H.F. Thermocouple, A.C./D.C. Moving Iron, A.C./D.C. Dynamometer

LABORATORY STANDARD INSTRUMENTS

D.C. Moving Coil, A.C./D.C. Dynamometer

CURRENT TRANSFORMERS • FREQUENCY METERS • ALL-PURPOSE TEST SETS

AIRCRAFT INSTRUMENTS • RATIOMETERS • TACHOMETERS

ELECTRICAL THERMOMETERS • WESTON STANDARD CELLS

'PHOTRONIC' PHOTO ELECTRIC CELLS • PHOTOMETERS

*

SANGAMO WESTON LTD. ENFIELD · MIDDLESEX

Telephone: ENfield 3434 (6 lines) and 1242 (6 lines). Grams: Sanwest, Enfield. Scottish Factory: Port Glasgow, Renfrewshire, Port Glasgow 41151

Branches: London, CHAncery 4971 · Glasgow, Central 6208 · Manchester, Central 7904 · Newcastle-on-Tyne, Newcastle 26867 Leeds, Leeds 30867 · Liverpool, Central 0230 · Wolverhampton, Wolverhampton 21912 · Nottingham, Nottingham 42403 Bristol, Bristol 21781 · Southampton, Southampton 25326

SANGAMO WESTON

SW/54

Fastest...easiest-to-clean electric cooker ever!

A NEW ADDITION TO THE MERCURY FAMILY

FOUR "QUICK-DISCS" give unsurpassed performance on the new CREDA MERCURY FOUR. This is cooking in the grand manner. Install a Mercury Four and let the Jones's *keep up with you!*

EASIEST TO CLEAN. All four quick-discs, exclusive to Creda, are **"sealed to the hob for easiest wipe-over cleaning".** The Creda Mercury cookers are by far the easiest to clean of any cookers available today.

SUPER FAST. All four quick-discs are very fast but one is specially boosted for fastest boiling ever and each is separately controlled to give just the heat you want, from a gentle simmer to a steady boil.

NEW EASY WORKING HEIGHT. The sensible new hob height of 33 inches (3 inch plinth available at small extra cost for those with 36 inch high kitchen units).

LESS STOOPING. Oven raised to more convenient height.

SEALED INNER GLASS DOOR and automatic oven interior light enables you to see "what's cooking" *without* loss of heat.

LARGE WARMING DRAWER separately heat-controlled with neat tuck-away storage for grill pan.

LUXURY too in the modern high splash plate and control panel.

LUXURY in the simple-to-set clock face Timer (for remote control cooking) and five-hour ringer.

LUXURY in the large fully automatic oven designed for perfection in timer-controlled cooking.

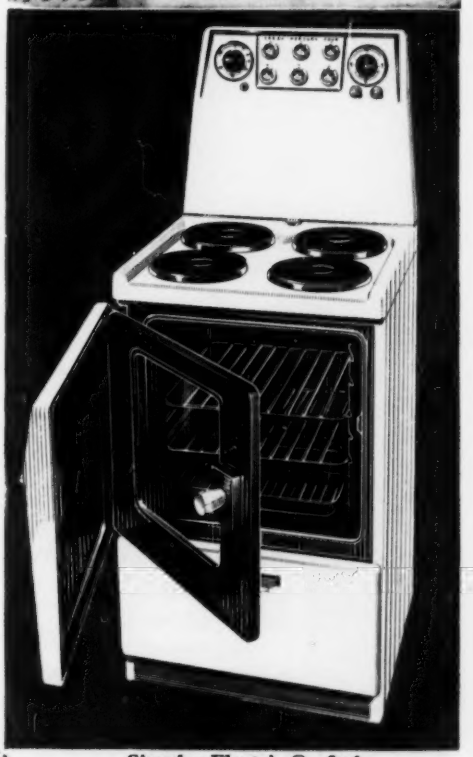
LUXURY in the family size even-heating grill. Six slices of toast at a time.

Outstanding value for money at 49 gns. No Extras

Other Mercury models from **34 gns. No Extras.**

Remember**—electric cookers carry **no Purchase Tax.

Make sure you see the complete range of Creda Mercury Cookers at your local electrical showroom.



Creda **mercury four**
THE ELECTRIC COOKER THAT'S MORE ADVANCED THAN EVER

Simplex Electric Co. Ltd.
Creda Works, Blythe Bridge, Stoke-on-Trent.
London Showrooms:
Creda House, 26/28 Binney Street, London, W.1

CA1c5/C1202 A THORN COMPANY

Casting
ANACOS
REGD
rods
wire
strand
copper-cadmium
FREDERICK SMITH & COMPANY
ANACONDA WORKS SALFORD 3 LANCS

THE BRITISH ELECTRICITY GRID UNDER CONTROL

● GENERATING STATIONS		○ SWITCHING STATIONS	
G1	Aberdeen ◉	S1	Abernethy (Transfer)
G2	Achanalt	S2	Beauly
G3	Allt-Na-Lairige	S3	Bonnibridge (Transfer)
G4	Cashlie	S4	Brechin
G5	Cassley	S5	Charleston
G6	Ceannacroc	S6	Craigiebuckler
G7	Clachan	S7	Errochty
G8	Clunie	S8	Fort Augustus ◎
G9	Dalchonzie	S9	Sloy
G10	Dounreay (Atomic)	S10	Keith
G11	Dundee ◉	S11	Kintore
G12	Errochty ◉	S12	Milton-o-Craigie
G13	Fasnakyle ◉	S13	Strathleven (Transfer)
G14	Finlarig	S14	Windyhill (Transfer)
G15	Glenmoriston		
G16	Grudie Bridge		
G17	Invergarry		
G18	Killin		
G19	Lairg		
G20	Lednock		
G21	Lochay ◉		
G22	Lubreoch		
G23	Luichart		
G24	Mossford		
G25	Orrin		
G26	Pitlochry(C.C.R.) ●		
G27	Quoich		
G28	Rannoch		
G29	Shin ◉		
G30	Sloy ◉		
G31	St Fillins		
G32	Sron-Mor		
G33	Torr Achilty ◉		
G34	Tummel		

△ EDINBURGH (NOSHEB H.Q.)
● CENTRAL CONTROL ROOM
◎ ◉ GROUP CONTROL CENTRES
(TRANSFER) NORTH TO SOUTH & VICE VERSA

THE NORTH OF SCOTLAND HYDRO ELECTRIC BOARD

The System Control Centre is located at Pitlochry in Perthshire, adjacent to Errochty Switching Station, to which it is connected by a S.T.C. multi-channel carrier on a cable telephone system. A power line carrier system is provided over the 132 kV lines on which is superimposed a network of S.T.C. frequency modulated voice frequency telegraph circuits over which all other functions are carried out — including telephone signalling, telemetering switch position indications, alarms and supervisory control.

S.T.C. has also played an important part in the remote control schemes for the Snowy Mountains (Australia), Owen Falls (Uganda), Aswan (Egypt) and Kariba (Rhodesia).

The North of Scotland Hydro Electric Board's area covers nearly 22,000 square miles and serves a population of over a million people. The System Control Centre is shown in the photograph below and presently controls 9 Group Control Centres each consisting of a number of Generating and Associated Switching Stations. Certain individual Power Stations and Switching Stations are also controlled. The equipment, to provide the Board with a centralised telecommunications and remote indication network, was manufactured and installed by Standard Telephones & Cables Limited.

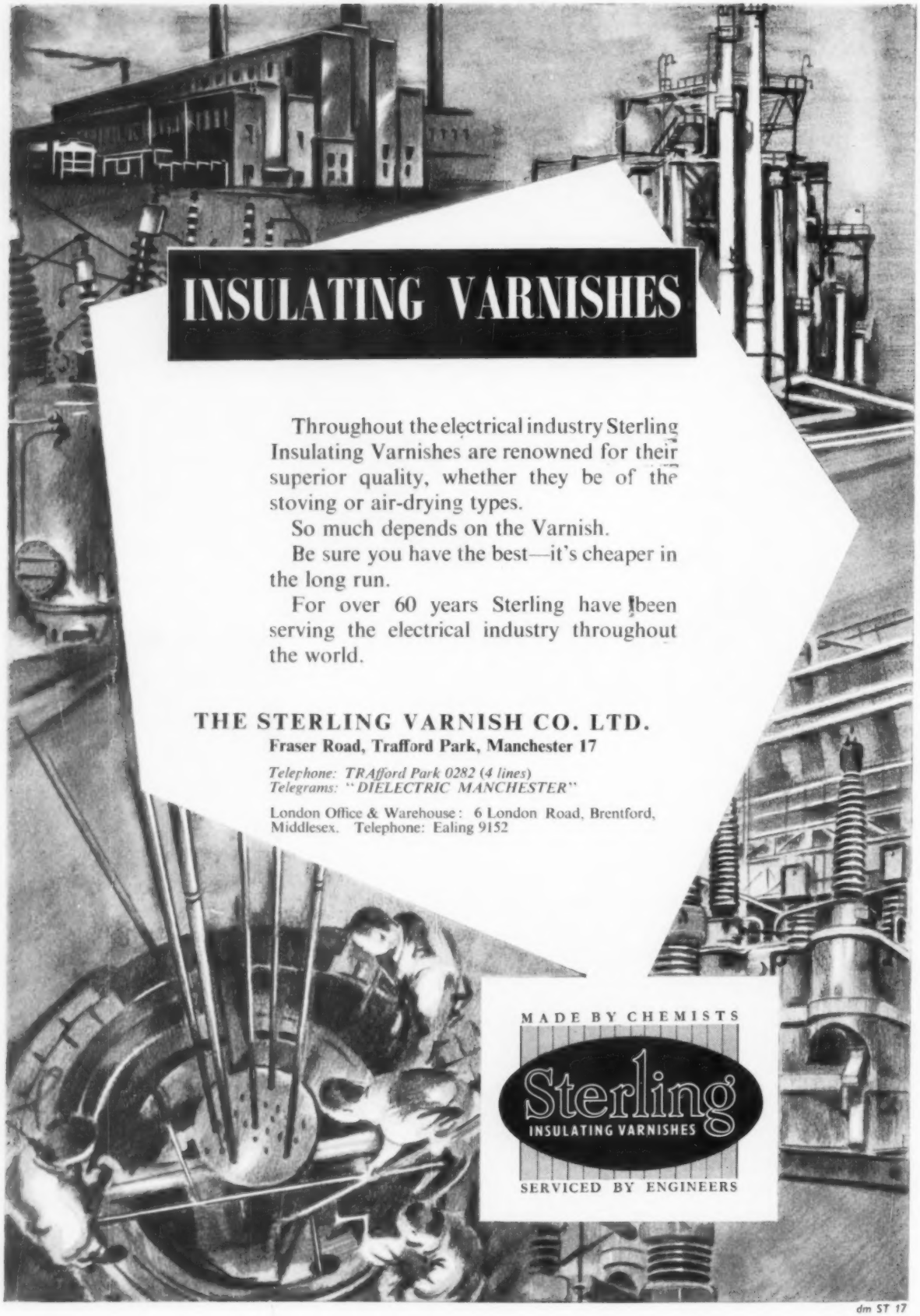
ELECTRONIC SYSTEMS GROUP

Standard Telephones and Cables Limited

Registered Office: Connaught House, Aldwych, London, W.C.2

INSTRUMENTATION AND CONTROL DIVISION

PROGRESS WAY · GREAT CAMBRIDGE ROAD · ENFIELD · MIDDLESEX


INSULATING VARNISHES
Throughout the electrical industry Sterling Insulating Varnishes are renowned for their superior quality, whether they be of the stoving or air-drying types.
So much depends on the Varnish.
Be sure you have the best—it's cheaper in the long run.
For over 60 years Sterling have been serving the electrical industry throughout the world.
THE STERLING VARNISH CO. LTD.
Fraser Road, Trafford Park, Manchester 17
Telephone: TRAfford Park 0282 (4 lines)
Telegrams: "DIELECTRIC MANCHESTER"
London Office & Warehouse: 6 London Road, Brentford, Middlesex. Telephone: Ealing 9152
MADE BY CHEMISTS
Sterling
INSULATING VARNISHES
SERVICED BY ENGINEERS
dm ST 17

Magnet wheel of a G.E.C. 62,500 kVA hydro-alternator for Aura Kraftanlegg, Norway.

LAMINATIONS
of all types, in all sizes and in all grades of material.

FERROSIL
hot-rolled and cold-reduced electrical sheet and strip, and hot-rolled transformer sheet.

ALPHASIL
cold-reduced oriented transformer sheet and strip.

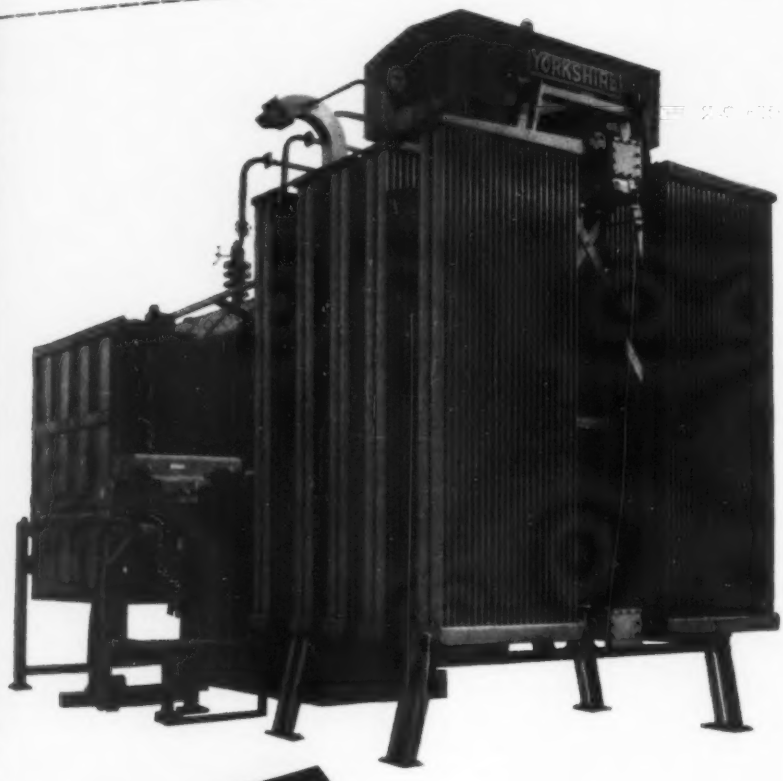
RICHARD THOMAS & BALDWINS LTD.

Lamination Works: COOKLEY WORKS, BRIERLEY HILL, STAFFS. Midland Section Office: WILDEN, STOURPORT-ON-SEVERN, WORCS.
Head Office: 47 PARK STREET, LONDON, W.1.

Our Cookley Works is one of the largest in Europe specializing in the manufacture of laminations for the electrical industry.

Y·E·T

Constructed by Careful Craftsmen



YORKSHIRE

transformers

We are specialists in the manufacture of **POWER TRANSFORMERS** for Generation, Transmission and Distribution. Every Transformer is entirely manufactured in our own works.

All sizes up to 75,000 kVA Voltages up to 150 kV

YORKSHIRE ELECTRIC TRANSFORMER CO. LTD
THORNHILL, DEWSBURY, ENG. *Tel.*: Dewsbury 1691-2

Printed for the Proprietors, THE BRITISH ELECTRICAL AND ALLIED MANUFACTURERS' ASSOCIATION (INCORPORATED), by WILLIAMS, LEA & CO., LTD., Clifton House, Worship Street, London, E.C.2.

Another 'first' for Ferranti

Ferranti Ltd. have received an order from the Central Electricity Generating Board through the Northern Project Group for the largest Transformers ever ordered from a manufacturer in this country by a British customer. The placing of this order demonstrates Ferranti's leading position in the Transformer industry. The contract is for two 310,000 kVA, 3 phase, 50 cycle double-wound Transformers for installation at Blyth 'B' Power Station, Northumberland, to step up the Generator voltage to 295 kV and to provide a direct connection to the Super Grid. The units are water-cooled and incorporate all the latest research and developments; they will be equipped with Ferranti Resistor Type On-Load Tap Change Gear.

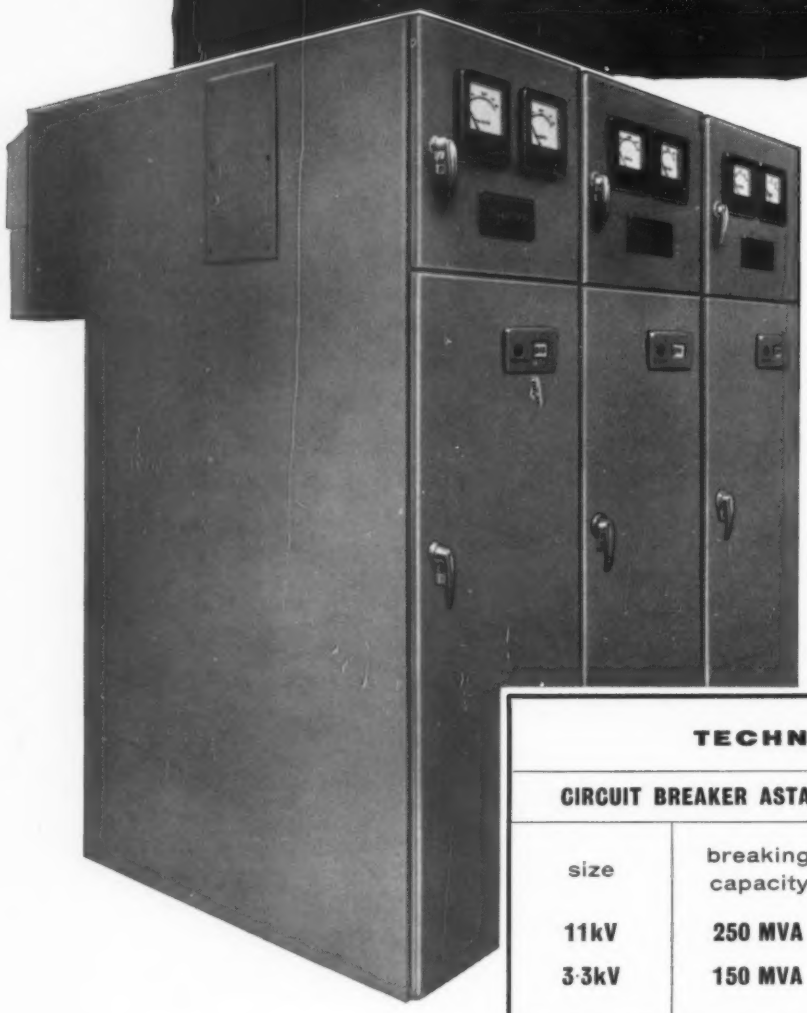
The Consulting Engineers are Merz & McLellan.

FERRANTI *first into the future*

FERRANTI LTD Head Office and Works: HOLLINWOOD · LANCASHIRE Telephone FAllsworth 2000
London Office: KERN HOUSE · 36 KINGSWAY · LONDON W.C.2. Telephone TEMple Bar 6666

FT229/2

THE NEW ELLISON HIGH TENSION SWITCHGEAR



DIMENSIONS

The overall dimensions of a basic circuit breaker unit have been reduced to the minimum permissible for easy accessibility. They are as follows:— 24″ wide, 6′ $4\frac{3}{4}$″ high and 4′ $9\frac{5}{8}$″ back to front. A voltage transformer adds 1′ $5\frac{9}{16}$″ to the height.

TECHNICAL DATA

CIRCUIT BREAKER ASTA CERTIFIED TO B.S. 116:1952

size	breaking capacity	making capacity	ASTA certificate
11kV	250 MVA	33·4 peak kA	3990
3·3kV	150 MVA	67 peak kA	3991

COMPLIES WITH B.E.B.S.–S2 and THE 250 MVA ADDENDUM

TRADE MARK

GEORGE ELLISON
LIMITED

PERRY BARR · BIRMINGHAM 22B

May we send further information?

841